Presented by

The Publishers

April 1896

Pam - Ind

SEWAGE DISPOSAL

IN THE

UNITED STATES

BY

GEO. W. RAFTER, M. Am. Soc. C. E.,

AND

M. N. BAKER, Ph.B.,

Associate Editor, *Engineering News*

NEW YORK

D. VAN NOSTRAND COMPANY

LONDON

SAMPSON LOW, MARSTON & COMPANY, Limited

1894

TROW DIRECTORY
PRINTING AND BOOKBINDING COMPANY
NEW YORK

DEDICATED

TO THE HEALTH AND PROSPERITY OF
AMERICAN CITIES AND TOWNS

PREFACE.

QUESTIONS of River Pollution and Sewage Disposal have assumed so much importance in this country that no excuse is necessary for putting forth an American treatise on the subject. The chief object, therefore, of this book is to specifically call the attention of sanitary authorities, engineers, and others interested in questions of public sanitation, to the fact that we have already accumulated a considerable stock of experience in sewage disposal in this country, and that for the future Americans, who wish to study the subject in detail, will not be obliged, as until recently was the case, to go abroad for the purpose.

In making this remark we do not wish to be understood as discouraging the study of foreign precedents in sewage disposal; on the contrary, it is cheerfully conceded, inasmuch as the necessity for sewage purification first arose abroad, that consequently the foreign engineers had the opportunity to attack the problem first, and we may very properly profit by their experience. The full idea is that the conditions here are generally quite dissimilar from those obtaining abroad, and that, with most of the feasible methods of sewage purification now in successful operation, the chances are decidedly in favor of quite as much profit from studying carefully the results obtained here as can be expected from the casual examination of executed projects abroad, which, after all, are for the most part only relatively applicable.

The experience at Worcester, Massachusetts, is a striking exemplification of the truth that in the end the American engineer must design works to suit his specific case. In the preliminary discussion at Worcester it was nearly universally assumed that, by reason of an identity of climatic conditions between Worcester and Danzig, the sewage irrigation fields of the latter city might be duplicated at Worcester, and results obtained quite as successful as those attending sewage farming at Danzig. But Mr. Allen took the ground that the climatic conditions were sufficiently dissimilar to render an extensive sewage farm at Worcester an experiment, relative to which it was impossible to predicate success from what had occurred at Danzig.

At South Framingham, Massachusetts, however, disposal by broad

irrigation and intermittent filtration is in operation on a comparatively large scale; and inasmuch as the distance from this town to Worcester is only twenty-three miles, we may hope to gain in a few years some useful experience from these two towns on the relative value of different systems of treatment at low temperatures. The extensive intermittent filtration works at Marlborough, Massachusetts, in the immediate vicinity, may also be looked to for interesting information on the same point.

An attempt has been made to present in Part I. the governing principles of sewage disposal with special reference to American needs; while in Part II. there have been given the salient features of the principal American sewage disposal works, with, so far as they can be obtained, reliable statements of cost of construction and operation. It is hoped that the information may be of use, not only to such sanitary authorities as Sewer Commissioners and Health Officers, but also to those engineers who are looking into the subject for the first time. We even venture to hope that it will prove of material benefit to the few engineers of ability and experience who have thus far designed most of the sewage disposal works of the country; for American knowledge of and practice in sewage purification is growing rapidly, and has never before been brought together with any degree of comprehensiveness.

Our references, citations of authorities, and quotations are drawn very largely from American sources of information. The reason for this is, as already indicated, that we need to know first of all about our own special conditions. At the same time we have not hesitated to use foreign data when necessary for the completeness of the discussion.

As conducing to a knowledge of our own special conditions, the experiments of the Massachusetts State Board of Health may be cited first of all. The views of a high English authority on the comparative value of these experiments have been referred to in the footnote on page 265, and it appears unnecessary to further elaborate this part of the subject. The work accomplished by our Agricultural Experiment Stations has also been freely drawn upon, with the result, it is believed, of furnishing a large amount of new data of special value in projecting American sewage disposal works.

Concluding this part of the subject, it is sincerely hoped that American engineers and physicists may, by their improvements and increase of accurate knowledge of sewage disposal, be able to pay back some portion of the obligation which we owe chiefly to English engineers, and investigators for our preliminary ideas in relation to sewage purification.

It will be noticed that the amount of original matter in the book is relatively small. This is partially owing to the use of the language of

the authorities drawn upon, instead of veiling its identity under slight verbal changes. For all this, of necessity many elaborate and valuable contributions to the literature of sewage disposal have been either condensed into a few sentences or dismissed with a brief reference. In all cases the aim has been to present as clearly and yet as briefly as possible the best available information on the subject under discussion and to indicate the sources of information.

Quoted matter has generally been indicated by the use of smaller type. Quotations have been freely made in Part I. in all those cases where the quoted matter appears necessary for a complete discussion, or where nothing can be added to what the various authors have originally written. In Part II. we have preferred to quote at length from available memoirs prepared by the engineers who have actually designed and constructed the different works, because these memoirs, by reason of embodying the results of personal experience, are more valuable than any mere abstract could be possibly made. We have assumed, in short, that the making of the ideal sewage disposal manual is to some extent a matter of discreet editing.

While we have used footnote references liberally, we have not attempted to make the references to any part of the subject absolutely complete. To do this would involve an amount of labor out of all proportion to the results. Nevertheless it is hoped that the references to original sources of information are numerous enough to enable any person wishing to go further into the subject than the limits of a volume of this character would permit, to find readily, so far as the American literature is concerned, practically all there is of value at the present time.

A word in regard to the joint authorship. In the fall of 1891 Mr. Rafter began, at the request of the publishers, D. Van Nostrand Co., the preparation of a Manual of Sewage Disposal in the United States. Early in 1892 Mr. Baker began the collection, largely by personal visits to existing purification works, of data in regard to executed works as the basis of a series of articles in Engineering News. Neither was aware of the work of the other until about July 1, 1892; at which time Mr. Rafter had nearly completed the task to which he had set himself, while Mr. Baker was just beginning the series of articles on executed works which have since appeared in the journal named. A comparison of data indicated that Mr. Baker's work on the executed projects, by reason of bringing the information more nearly down to date, would add to the completeness of the book, and accordingly arrangements were made for joining forces. In addition to considerably extending Part II., Mr. Baker has also made material additions to Chapter VII. in Part I., and has revised the whole work so far as necessary to include any additional information in his possession.

This revision brings the work down to June, 1893, as completely as is practicable in a work of such a character, and the additions include descriptions of all the town and city purification works known to be in operation to date. That the book is now other than relatively complete is not pretended; it is merely put forth as representing the best effort in this direction of which the joint authors are capable at this time.

Our sincere thanks are due to the many engineers who have cordially responded to our requests for information, as well as to the superintendents of a number of public institutions to whom we have applied. Among engineers to whom we are specially indebted may be mentioned Col. Geo. E. Waring, Jr., M. Inst. C.E., J. Herbert Shedd, M. Am. Soc. C.E., Samuel M. Gray, M. Am. Soc. C.E., and Chas. A. Allen, M. Am. Soc. C.E.

The major portion of the illustrations have been prepared, specially for this work, under the direction of Mr. F. P. Burt, of Engineering News. For the illustrations not so prepared, we are indebted to The American Society of Civil Engineers, The Engineering Magazine, The Engineering Record, and Engineering News.

G. W. R.
M. N. B.

NEW YORK, June 1, 1893.

CONTENTS.

PART I.

DISCUSSION OF PRINCIPLES.

CHAPTER I.

PRELIMINARY DISCUSSION.

CHAPTER II.

THE INFECTIOUS DISEASES OF ANIMALS.

CHAPTER III.

ON THE POLLUTION OF STREAMS.

CHAPTER IV.

THE SELF-PURIFICATION OF RUNNING STREAMS AND THE RATIONAL VIEW IN RELATION TO THE DISPOSAL OF SEWAGE BY DISCHARGE INTO TIDE-WATER.

CHAPTER V.

THE COMPOSITION OF SEWAGE MUDS.

CHAPTER VI.

LEGAL ASPECTS OF THE CASE.

CHAPTER VII.

QUANTITY OF SEWAGE AND VARIATION IN RATE OF FLOW.

CHAPTER VIII.

GENERAL DATA OF SEWAGE DISPOSAL.

CHAPTER IX.

DISCHARGE INTO TIDAL OR OTHER LARGE BODIES OF WATER.

CHAPTER X.

ON NITRIFICATION AND THE NITRIFYING ORGANISM.

CHAPTER XI.

CHEMICAL PRECIPITATION.

CHAPTER XII.

BROAD IRRIGATION.

CHAPTER XIII.

ON SILOS AND THEIR USE IN SEWAGE FARMING.

CHAPTER XIV.

INTERMITTENT FILTRATION.

CHAPTER XV.

CHAPTER XVI.

THE DISPOSAL OF MANUFACTURING WASTES.

CHAPTER XVII.

ON THE TEMPERATURE OF THE AIR AND OF NATURAL SOILS, AND ITS RELATION TO SEWAGE PURIFICATION BY BROAD IRRIGATION AND INTERMITTENT FILTRATION.

CHAPTER XVIII.

CHAPTER XIX.

CHAPTER XX.

PART II.

DESCRIPTIONS OF WORKS.

CHAPTER XXI.

CHAPTER XXII.

CHAPTER XXIII.

CHAPTER XXIV.

CHAPTER XXV.

CHAPTER XXVI.

CHAPTER XXVII.

CHAPTER XXVIII.

CHAPTER XXIX.

CHAPTER XXX.

CHAPTER XXXI.

CHAPTER XXXII.

CHAPTER XXXIII.

CHAPTER XXXIV.

CHAPTER XXXV.

CHAPTER XXXVI.

CHAPTER XXXVII.

CHAPTER XXXVIII.

CHAPTER XXXIX.

CHAPTER XL.

CHAPTER XLI.

CHAPTER XLII.

CHAPTER XLIII.

CHAPTER XLIV.

CHAPTER XLV.

APPENDICES.

LIST OF ILLUSTRATIONS.

PLATES.

FIGURES IN TEXT.

LIST OF TABLES IN PART I.

SEWAGE DISPOSAL IN THE UNITED STATES.

PART I.

DISCUSSION OF PRINCIPLES.

CHAPTER I.

PRELIMINARY DISCUSSION.

Definition of Terms.

One occasionally meets a misuse of the terms sewerage and sewage, and by way of giving a clear idea of the thing discussed we may properly begin a treatise on sewage disposal with a definition of the leading terms. By *sewerage*, as here used, we refer to the general process of removing the liquid and solid wastes of the human economy by water-carriage, while a *sewer* is the conduit through which, by the medium of water, such removal is effected; *sewage*, on the other hand, will be used as the generic term not only for the combined water and waste matters flowing in sewers, but for the mixed solid and liquid matters handled by a pail or pneumatic system as well.

Sewage disposal in its broadest sense may be taken, then, as referring to any disposal or treatment of sewage which renders it innocuous to human beings; it may include disposal by discharge into tidal or other large bodies of water, utilization in sewage farming, or by burying, as is sometimes practised with pail systems.

Classification.

With this definition, methods of sewage disposal may be classified under the following heads:

I. The use of privies and cesspools.
II. Collection by pail systems.

III. The pneumatic systems of Liernur, Berlier, Shone, and others.
IV. Simple subsidence or sedimentation.
V. Simple filtration through some artificial substance, as coke, excelsior, or ashes.
VI. Discharge of crude sewage into tidal or other large bodies of water.
VII. Chemical precipitation.
VIII. Broad irrigation.
IX. Intermittent filtration.
X. And finally electrolysis; although this method, while promising good results, must still be considered as in the experimental state.*

The first three methods will not be considered at all in this treatise,

* Mechanical filtration may be also possibly regarded as another method of sewage disposal, and the Farquhar-Oldham filter is cited as a device of this character, which apparently has limited application to small quantities of sewage, as, for instance, to the sewage of detached houses. So far as the writer knows, it has never been successfully used on a large scale in the United States. An unsuccessful trial was made at the Mystic Valley Sewage Disposal Works a few years ago. (See reference to same in Part II.)

The Lortzing system of combined mechanical and chemical purification may be referred to.

According to the Inventor's Circular the following combinations of advantages have been successfully incorporated in this filter :

1. The mechanical and chemical treatments are strictly separated, all impurities capable of being eliminated mechanically being first extracted before recourse is had to chemicals.
2. By thus reducing the quantity of chemicals used, not only their cost is saved, but the quantity of the final products is diminished, and therefore the expense of dealing with them reduced to a proportionate degree.
3. By the provision of means for circulating the same chemicals repeatedly, it is possible to employ certain difficultly soluble chemicals, which at present cannot be used at all, and the cost of which is merely nominal. The small cost of these materials is, however, only part of the advantage gained by their use ; a further great advantage is, that being difficultly and slowly soluble, they act at first as mechanical precipitants ; and afterwards, as they slowly dissolve in their course of circulation, their chemical action comes into play.
4. The working of the apparatus is almost automatic, and requires very little manual labor.
5. Owing to its special mechanical principles of construction and its continuous working, no interruption being necessary for the purpose of clearing out the sediment, the space taken up by the apparatus and buildings, as compared to the quantity of work done, is reduced to a small fraction of what is now necessary.
6. Owing to the provision of natural filter-beds within the apparatus, which are formed by the sedimentary matter itself, the prime cost of additions, as well as the disadvantage of their unduly increasing the bulk of the by-products, is saved.
7. Such filters act automatically, and can be continuously and expeditiously cleaned out without any stoppage of the working. Owing to the sediments being thus removed from day to day, no time is given for decomposition and its injurious consequences.
8. It will be clear that, as the quantity of mechanical and chemical admixtures during the process is very greatly reduced, the really valuable ingredients of the sewage are contained in the final by-products in a concentrated form, which transforms these products into a valuable marketable commodity, whilst for the converse reason the products attained by the present method are rarely worth the cost of transport, and often absolutely valueless.

For further details of the Lortzing system see (1) the inventor's circular, "Improvements in the Method of, and Apparatus for, Purifying the Water-Carried Sewage of Towns," etc.; (2) an abstract of this circular, with the illustrations, may be found in Eng. News, vol. xxii. (1889), p. 362.

The Lortzing system appears to be, so far as the actual purification process is concerned, essentially a chemical treatment, to which a certain amount of mechanical detail has been added. It also illustrates the recent development of chemical treatment in vertical tanks, for further information regarding which see Chapter XI., on Chemical Precipitation.

except that a short chapter is included in Part II. descriptive of the pail system at Hemlock lake, N. Y.*

Sedimentation and simple filtration will not be considered any further than as, at times, useful adjuncts to the more positive systems of purification. Experience in England has amply demonstrated that they have little claim to be considered systems of purification by themselves.

In the case of disposal into tidal or other large bodies of water the problem to be solved is, in its engineering features, purely one of physics, while that involved in disposal by chemical precipitation, broad irrigation, or intermittent filtration, may be considered as also including, in addition to the physical features, problems in chemistry and biology. With this understanding it may be premised that the chief object of the present work is to treat of sewage disposal by chemical precipitation, broad irrigation, and intermittent filtration, and that only a relatively small amount of space will be devoted to the discussion of disposal into tidal or other large bodies of water.

Again, electrolysis will not be discussed in this work.†

Sewage Disposal a New Subject in the United States.

‡ Sewage disposal, in its practical application, is comparatively a new subject in the United States; but the rapid growth of population, with its movement into cities and towns, has led to a large number of cases throughout the country in which sewage is discharged into streams, ponds, or lakes which are also the sources of public water

* The pneumatic systems have been thoroughly described elsewhere, and inasmuch as it is impossible, at the present time, to either add anything to what has already been said in regard to such systems, or give any examples of their use in American practice, it is sufficient to merely refer the reader to some of the sources of information which are accessible in American sanitary literature, namely:

(1) The Sanitation of Cities and Towns, and the Agricultural Utilization of Excreted Matters. A Report on Improved Methods of Sewage Disposal and Water Supplies. By C. W. Chancellor, M.D., Sec. Md. St. Bd. Health, 1887. Pamphlet, 176 pages.

(2) Proposed Plan for a Sewerage System, and for the Disposal of the Sewage of the City of Providence. By Samuel M. Gray, City Engineer. 1884, pp. 22–30.

(3) Berlier System, &c., Eng. and Bldg. Record, vol. vi., p. 376; vol. x., p. 411.

(4) Col. Geo. E. Waring's Sanitary Drainage of Houses and Towns, where may be also found the main facts about dry earth systems, vaults and privies, and pail systems.

Wm. Paul Gerhard's The Disposal of Household Wastes (No. 67 Van Nostrand's Sci. Ser.) may be also consulted.

† The available information in regard to the electrolysis of sewage may be found in (1) Eng. News, vol. xxi., p. 339, and vol. xxii., p. 387; (2) Eng. and Bldg. Record, vol. xiii. (1890), p. 114; (3) Sci. Am. Sup., May 4, 1889, Nov. 23, 1889, and Apr. 25, 1891.

See also description of the Hardy system of sewage purification, in which electrical treatment is proposed as an adjunct, in Eng. News, vol. xxi. (1889), p. 88.

‡ A portion of the following discussion originally appeared (1) in a paper on Sewage Disposal in the United States, in The Eng. Mag., vol. ii., No. 4 (Jan. 1892); and (2) in a Report to the Trustees of the Weston, W. Va., State Insane Hospital. In Jour. W. Va. House of Delegates for Feb. 18, 1891. Both by Mr. Rafter.

supplies. The drinking of water containing human excrement is a disgusting and dangerous practice, and we cannot hope for immunity from communicable diseases until the custom is entirely discontinued. The fact that there are a number of places where this condition exists has enforced the necessity for sewage purification, and made it a vital question demanding immediate solution.

As always happens when new conditions arise, numerous remedies are proposed, many of them bearing little or no relation to the case to be treated; and by way of assisting to a clear understanding of the present state of the whole question, it is proposed to give herein a presentation of (1) some of the main reasons why sewage purification may be considered in many cases an imperative necessity; (2) a brief statement of the approved methods of effecting sewage purification; and (3) an account of the principal sewage purification works, already in operation in this country, together with a description of a few notable disposal works designed to remove sewage without purification.

In the beginning, then, we need to understand clearly why sewage purification is, in many cases, an imperative necessity; and by way of assisting to such understanding, we will present a short statement of the leading facts, as now understood, in relation to the causation of communicable diseases, and the bearing of such facts on sewage disposal.

The Germ Theory of Disease.

Certain diseases of men and animals are communicable from one individual to another, and the modern studies in bacteriology show that some of them are not only communicable between individuals of the same species, but are interchangeable between animals and men, and between men and animals.

The germ theory of disease as announced in the last few years is the most rational explanation of the causation of communicable diseases that has yet been advanced, and, without asserting its absolute correctness, it may be still said that at the present time all advanced sanitarians assume its correctness, and the best sanitary work is executed on the supposition that the said theory is essentially correct. It is important that this be thoroughly understood, because the assumption of essential correctness of the germ theory forces upon sanitary authorities the responsibility of not only taking certain precautions and providing preventive measures always, but leaves upon them the responsibility of possibly imperilling human life in case of neglect.

The germ theory assumes that the active causes of communicable or contagious diseases are minute, living organisms, for the most part capable of independent life both within and without the animal body.

They belong among the *Schizomycetes*, or fission-fungi, embracing the lowest and least developed forms of life in the vegetable kingdom, and they may hence be considered the very simplest forms of plants. Some of the forms are bacilli, micrococci, spirilla, vibrios, all of which may be referred to as bacteria.

Many forms of bacteria are harmless and must be looked upon as the beneficent friends of man, doing him many a good turn which otherwise he would find it difficult to accomplish. Others are the morbific causes, when they gain access to the human economy, of the various infectious or communicable diseases. Attention may be here directed to the fact that the bacteria, although microscopic in size, are still, so far as the evidence goes, divided into distinct species, and by consequence each contagious disease has its own specific germ, which must be present in every case before that particular disease can be developed.

Once introduced into the animal body, however, the specific germ, after a period of incubation, finally grows and multiplies enormously; so that while a single germ, or the least atom of infectious material, serves to inoculate a disease in a susceptible person, the contagious matter produced in the course of the disease may be sufficient to inoculate many thousands. In each special disease, the contagion multiplies chiefly in the particular tissues which are especially subject to its action, and the infective germs are cast off from the body with the secretions of those tissues. Thus, in typhoid fever, the seat of the disease is such that the infectious matter passes away in large quantities in the dejections from the bowels.

Typhoid Fever.

The period of incubation in typhoid is a long one, of from 14 to 20 days, while the course of the disease after full development is usually as many more. Frequently this disease is of so mild a character, that the person having it is unaware of its presence. This constitutes a walking case, but the dejections from such are quite as dangerous as from the severest cases. A walking case of typhoid may go about for a number of weeks, sowing the germs of the disease broadcast with every dejection, absolutely without knowledge of the fact, and with no unpleasant sensation other than that which accompanies being slightly unwell.

How Typhoid Germs Gain Access to the Human Economy.

The germs of typhoid usually gain access to the animal economy through the medium of drinking-water, although the germs may be

present in the air of sewers receiving the dejections of typhoid patients, as has been demonstrated by Dr. Victor C. Vaughan, of the University of Michigan. When this is the case, breathing the sewer air will lead to the production of the disease, as happened at the Jackson prison, in a case studied by Dr. Vaughan.*

Usually, however, the germ of typhoid, by reason of passing from the body of the patient in the dejections, is liable to be present in the water we drink rather than in the air we breathe, and the length of time the germs will survive, after passing from the human body into a stream of water as a constituent of sewage, becomes a practical question of considerable importance in connection with sewage disposal, especially where a stream of moderate size receives sewage at a given point, and is at the same time, lower down, the source of a public water supply.

Responsibility of Purification.

The question, Upon whom does the responsibility of purification rest? has been raised in a number of cases, and from the foregoing considerations it may be concluded that it rests upon every community, manufacturing establishment, public institution, or individual whose sewage outfall is into a stream, pond, lake, or other body of water, which either is or may be the source of a public water supply at any point fairly within the influence of the inflowing sewage. In this view, the further question at once arises as to what may be considered the legitimate limit of influence; to this a definite answer is afforded, in one case, by some experiments on the vitality of the germ of typhoid fever, as detailed by Hiram F. Mills, A.M., C.E.†

Typhoid Fever at Lawrence and Lowell.

In the month of November, 1890, the Massachusetts health returns indicated that the number of deaths by typhoid fever in Lowell far exceeded that of the whole city of Boston. The returns also showed a rapid increase at the same time in Lawrence, and, as no similar increase appeared in the other cities of the State, the State Board of Health made the matter the subject of special investigation in these two cities. Lowell has a population of 77,696, Lawrence 44,654, and Boston 448,477, all in 1890. Lawrence and Lowell are on the Merrimac river, Lawrence being nine miles down the river from Lowell. Both cities take their water supply from the Merrimac, and the crude sewage of Lowell is discharged into the same stream a short distance below

* 16th An. Rept. Mich. St. Bd. of Health, pp. 186–194 (1888).

† 22nd An. Rept. of the Mass. St. Bd. of Health (1890). Typhoid Fever in its Relation to Water Supplies, by Hiram F. Mills, A.M., C.E., pp. 525–543.

the Lowell water supply intake. A probable cause of the contamination of the Lowell water supply at this time was found in the discovery of the discharge of the dejections of typhoid patients into Stony brook, a tributary of the Merrimac, three miles up stream from the Lowell water-works intake.*

The Bacillus of Typhoid Fever.

It was also found that such discharge was, in proper sequence of time, followed by a rapid increase in the number of deaths from typhoid in Lowell; the increase there being further followed by an alarming increase in the number of deaths from typhoid in Lawrence. In December, bacteriological examinations of water drawn from the service pipes in Lawrence resulted in finding the bacillus of typhoid in the Lawrence supply. The bacillus of typhoid, or, as it is frequently called, Eberth's bacillus, is a rod-like bacillus with rounded ends. It is a plant with normal specimens $\frac{1}{10000}$ in. in length and about $\frac{1}{30000}$ in. in diameter. At the ends are hair-like appendages, technically called cilia. In cases of typhoid these bacilli multiply in enormous numbers, the seat of their greatest activity being in the Peyers' glands, although they have also been found in the mesenteric glands, larynx, and lungs of patients dead of typhoid. The typhoid germs are propagated either by fission or from spores. In propagation by fission each rod divides into two, each of which, after attaining maturity, again divides, and so on. Multiplication by spores is not yet fully understood, though in a general way it may be stated that spores form in the interior of bacilli, after the manner of spore multiplication in other cryptogams. The spores are much smaller than bacilli, and can only be seen with the most powerful objectives known to modern microscopists. It is probable that spores, when once formed, possess the power of survival under very adverse conditions, while the bacilli, by reason of possessing less vitality, more easily succumb.†

Typhoid Fever a Preventable Disease.

The statement may be made that typhoid fever is, in the fullest sense, a preventable disease. Keeping it out of the food we eat, the air we breathe, or the water we drink, is an absolute preventive; or, if

* Nashua and Manchester, New Hampshire, and a number of other towns on the river above Lowell also discharge crude sewage into the Merrimac.

† For discussion of formation of typhoid spores, with references to the literature and history of the subject, see paper, Experimental Studies on the Causation of Typhoid Fever, with Special Reference to the Outbreak at Iron Mountain, Michigan, by Vaughan and Novy; 15th An. Rept. Mich. St. Bd. Health (1887), pp. 2–11; also, The Specific Organism of Typhoid Fever, by Geo. W. Fuller, S.B., Technology Quarterly (Boston), vol. iv., No. 2, July, 1891.

An extended bibliography of the bacillus of typhoid fever is given in Sternberg's Manual of Bacteriology (1892), pp. 808–11, which includes 82 references to different papers, etc.

present in either, its destruction before allowing it to enter the human body is equally a preventive. Water, milk, or other drink or food suspected of containing it, should undergo a degree of heat equivalent to the boiling point of water for at least 30 minutes, as experience has shown that this will more than kill the most refractory spores.*

Returning to the Massachusetts Board's investigation of the epidemics of typhoid at Lowell and Lawrence, the practical question is at once raised as to whether (1) the numerous cases in Lowell may be justly ascribed to the known contamination of Stony brook above the Lowell water-works intake; and (2) whether the cases at Lawrence are also due either to the same cause, or, further, to an accession of typhoid germs in the water of the Merrimac river from the sewers of Lowell, which presumably received the dejections of many persons suffering from the disease in that town? The answer to both questions, as given in the report, is a decided yes, and we may now inquire whether typhoid germs, which grow in the human body at blood-heat, will survive in water only a few degrees above freezing long enough to pass, in the ordinary flow of the river, from the Lowell sewers to the Lawrence intake, thence through the distribution pipes to the services, thence into the houses, and finally into the bodies of the citizens of Lawrence. The temperature of the river water in November, 1890, was from 45° to 35°.

Taking the mean velocity of the river, it is found that the time from the Lowell sewer outfall to the Lawrence water-works intake is eight hours. Entering the reservoir the same day, the water would certainly go to the consumers through the service pipes in from a week to ten days; and the inquiry is narrowed to finding out whether the typhoid germ would live from seven to ten days in the Merrimac river water when at a temperature of from 45° to 35°.

Vitality of the Typhoid Bacillus.

To settle this interesting question, the Massachusetts Board made a series of experiments by inoculating water from the Lawrence service pipes with typhoid germs, and keeping it in a bottle surrounded by ice at near the freezing point for a month. Each day one cubic centimetre was taken out, and the number of typhoid germs therein determined by the usual culture methods. The number was found to decrease from day to day, although some survived 24 days as follows:

	Germs.
On the first day there were	6,120
On the fifth day there were	3,100

* Disinfection and Disinfectants: Their Application and Use in the Prevention and Treatment of Disease and in Public and Private Sanitation. By the Committee on Disinfectants appointed by the American Public Health Association.

On the tenth day there were	490
On the fifteenth day there were	100
On the twentieth day there were	17
On the twenty-fifth day there were	0

Limit of Influence in the Merrimac River.

It appears, then, for the purpose of illustrating the subject, we may say that in the Merrimac river the limit of influence of the sewage of the city of Lowell is fairly the point reached by the flowing water in 25 days after passing Lowell, the possible effect of dilution and sedimentation, the antagonism of the non-pathogenic bacteria, and the purifying effect of minute plants and animals in reducing the danger, not being here taken into account. The Merrimac river flows the nine miles from Lowell to Lawrence in eight hours, or at the rate of $1\frac{1}{8}$ miles per hour. Twenty-five days is 600 hours, and it is accordingly found, with the limitations noted, that a flow of 675 miles may occur before the Merrimac river can be considered perfectly free from the typhoid germ, if once inoculated, in the month of November. Enough is known of the persistency of vitality of the typhoid spore to justify assuming that the legitimate safe limit of influence in this stream will be quite as great as indicated in the foregoing, although there are modifying circumstances which will be referred to in some of the following chapters.

Table No. 1 gives the statistics of this epidemic of typhoid fever at Lowell and Lawrence.*

Table No. 1.—Statistics of Typhoid Fever in the Cities of Lowell and Lawrence, Mass., September, 1890, to January, 1891, inclusive.

Month.	Lowell. Pop., 77,605.				Lawrence. Pop., 44.559.	
	Deaths.	Deaths per 100,000 population.	Cases.	Cases to one death.	Deaths.	Deaths per 100,000 population.
September, 1890	8	10.31	47	5.6	3	6.73
October	10	12.88	95	9.5	3	6.73
November	28	36.08	171	6.1	7	15.71
December	26	33.51	159	6 1	19	42.64
January, 1891	19	24.48	78	4.3	19	42.64
Totals	91	117.26	550	....	51	......

Limit of Influence in Lakes and Ponds.

In the case of a lake or pond the limit of influence will be more restricted than in a running stream, though it must be stated in this con-

* Derived from (1) Mr. Mills' paper in 22nd An. Rept. Mass. St. Board of Health; (2) from a Report upon the Sanitary Condition of the Water Supply of Lowell, Mass., presented to the Water Board of Lowell, April 10, 1891, by Wm. T. Sedgwick, Professor of Biology, etc.

nection that the usual hydrographic observations of direction of water currents, as indicated by floats for a few days only, are utterly without significance so far as a rational solution of the problem of legitimate influence in any given case is concerned. Such observations must be carried on in conjunction with biological and chemical studies for a considerable period of time, and when so carried on will undoubtedly result in showing that the limit of influence in large lakes is much greater than has thus far been generally assumed.

The Case of Schenectady, Cohoes, West Troy, and Albany.

Professor William P. Mason has given in a recent paper an account, pertinent to the present discussion, of a series of epidemics of typhoid fever in a number of towns supplied with water from a sewage-contaminated stream.*

The stream in question is the Mohawk river, which receives the sewage of nearly every large town on its banks, several of them, as for instance Rome, Utica, Little Falls, Amsterdam, and Schenectady, having complete sewerage systems which discharge considerable quantities of crude sewage directly into the stream.

In July, 1890, a marked increase in the amount of typhoid fever was noted at Schenectady, and from that time to the middle of April, 1891, about 300 cases were reported, of which 70 were fatal. The health officer of the town is of the opinion that many of the milder cases were never reported, so that in reality the total number of cases was considerably in excess of 300. The population of Schenectady is, according to the census of 1890, 19,902.

The entire water supply of the city, amounting to 2,200,000 gallons, is now derived from the Mohawk river by direct pumping. Previous to 1887 the supply had been taken from a filter gallery near the river, but in that year extensions were made and the supply drawn from a crib in the middle of the river.

The water supplies of the towns of Cohoes and West Troy are also derived from the Mohawk river, while that of Albany is partly from the Hudson river, the balance being from inland lakes. Waterford, Lansingburgh and Troy, which are in the immediate vicinity, draw their public supplies from the Hudson above the mouth of the Mohawk; a portion of the public supply of Troy is from lakes to the back of the town by gravity. The approximate locations of the several intakes are shown by the squares on the map, Fig. 1.

The populations of these towns are: Waterford, 5,400; Lansingburgh,

* Notes on some Cases of Drinking-Water and Disease. By William P. Mason. Jour. Frank. Inst., Nov. 1891. Reprint, pp. 6–9.

10,550; Cohoes, 22,509; West Troy, 12,967; Troy, 60,956; Albany, 94,-923; total, 207,305.

There is also a town of a population of 4,463 on Green Island, which derives its water supply from a filter gallery.

In October, 1890, an epidemic of typhoid began in Cohoes, and continued until the middle of March, 1891. Altogether there were about 1,000 cases (1 in every 22.5 of the population); fortunately they were mostly mild in character, resulting in very few deaths.

In West Troy an epidemic of typhoid began in the latter part of November, 1890. On about December 15, 50 cases were reported. Of these 42 used Mohawk river water, the remainder well water. On December 20, the Mohawk supply was discontinued, and arrangements made for a supply of filtered water from Green Island, which had no

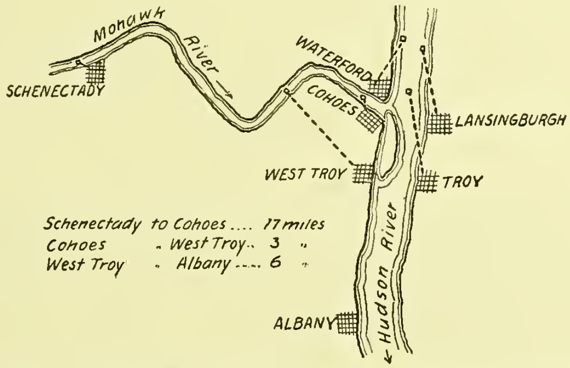


FIG. 1.—TOWNS AND WATER-WORKS INTAKES AT AND NEAR JUNCTION OF HUDSON AND MOHAWK RIVERS.

typhoid. In one week the report of new cases showed 15, while in two weeks but 1 was reported. On returning to the Mohawk supply, in the middle of January, a slight increase was observed. The total number of cases in West Troy exceeded 100.

An epidemic of typhoid began at Albany in the latter part of December, 1890, and continued during January, February, and March, 1891. A total of 411 cases were reported, but this figure is stated to be far below the real fact. Of the 411, only 18 are reported as occurring in the district supplied with water by gravity from the inland lakes.

Waterford, Lansingburgh, and Troy, whose entire water supplies are from fairly uncontaminated sources, were ordinarily free from typhoid during this period. The same is true of Green Island, the water supply of which is filtered from the Hudson river by means of a filter gallery.

The statistics of this epidemic, while not very complete, are of the greatest interest. They show that in a total population of 150,000 liv-

ing in several towns, all of which are supplied with a grossly contaminated water, the number of cases of typhoid occurring in a few months was over 1,800, or about 1 in every 84 persons. At the same time, in a similarly situated adjacent population of about 77,000, with an uncontaminated water supply, very few or no cases at all occurred.

It will be understood that the upper Hudson is only slightly contaminated with sewage.

Why Crude Sewage should be Kept Out of Streams.

Facts and discussions of the character of the foregoing lead to the conclusion that, as a mere matter of ordinary prudence, it is unsafe to allow raw sewage to flow into streams which are, at any point below where the sewage flows in, the source of a public water supply. The question of production of a nuisance by causing bad odors along the stream is the least important part, and in many cases it is certain that no material effluvium nuisance is ever created. Usually a minimum volume of flow in a stream of about ten times the volume of sewage will be sufficient to prevent this.*

List of Water-borne Communicable Diseases.

Returning to the general question of infectious diseases, we may note that the most important diseases which are usually water-borne, but of which the germs may be present in the air of sewers receiving the dejections of patients, are:

Typhoid fever,	Cholera,
Diarrhœa,	Dysentery.

In the case of these infectious water-borne diseases, it may be laid down as a fundamental proposition that the dejections of patients sick with them should never be allowed to pass into the sewers until they have been thoroughly sterilized by treatment with a proper disinfectant. Such treatment should be used as an additional precaution, as a mere matter of justice to any human being wishing to use the water of a sewage-contaminated stream for drinking, and it should be further used absolutely without reference to whether or not the sewage into which the dejections are discharged is to be treated at disposal works. The only exception to this rule may be found in the case of discharge directly into tide water.

Disinfection of Dejecta.

The American Public Health Association in 1884 appointed a committee to investigate the subject of disinfectants; a series of experi-

*Notes on the Pollution of Streams. By Rudolph Hering, C.E., Trans. Am. Pub. Health Assoc., 1887. Also Eng. and Bldg. Record, vol. xvii., p. 228.

ments were instituted and a valuable report was made. Among many other recommendations, the committee say, that for disinfecting excreta in the sick room there may be used—(1) chloride of lime in four per cent. solution (five ounces to one gallon of water); (2) mercuric chloride in solution, 1 to 500 (two drachms of mercuric chloride to one gallon of water). In order to give the mercuric chloride solution a distinct color as a guard against mistakes, two drachms of permanganate of potash may be added to each gallon when it is mixed in stock. The label should bear the word "poison" as an additional precaution against mistakes.

The dejections having been received in a vessel, an amount of either (1) or (2) equal to the quantity of dejections should be added, and after thorough stirring the whole allowed to stand for at least one hour. The mixture may then be safely permitted to go into the sewer.*

Of these two disinfectants the chloride of lime solution is the more certain in its application to excrement, provided fresh chloride of standard strength is used. It has the disadvantage that the dry chloride loses its strength quickly on exposure, and when there is doubt on this score the quantity of chloride per gallon of water may be increased.

The mercuric chloride solution is, however, certain in its effects, provided the precaution is always taken to thoroughly stir the excrement until every minute particle is brought into contact with the mercuric chloride solution. When not thoroughly stirred there is a tendency to the formation of an insoluble coating, by the action of the mercuric chloride on the albuminous constituents of the excrement, with the result that the germ material in the interior of the masses may remain entirely unaffected, and still capable, when liberated, of propagating disease the same as before disinfection. The chloride of lime, on the contrary, has a tendency to disintegrate the masses of fecal matter, thus bringing every particle in contact with the germ-destroying material.

Efficient disinfection of the dejections of typhoid and other patients may be accomplished by the use of either of these formulæ, due regard being given always to the precautions indicated in the foregoing.

Importance of Disinfection.

In illustration of the importance of disinfection of dejecta from patients suffering from typhoid fever and other water-borne communicable diseases before allowing them to pass into sewers, it may be stated that the most efficient means of purifying sewage yet known, intermittent sand filtration, cannot be depended upon to absolutely re-

* Report of Committee on Disinfectants, *loc. cit.*

move *all* the bacteria. Such means of purification will, however, ordinarily remove at least 99 per cent., and among those removed are presumably a large proportion of the disease germs, if any are present, thereby reducing greatly the chance of infection in any given case; but we cannot yet assume complete removal of all disease germs, especially of the more hardy varieties, as for instance the spore of typhoid fever. An experiment at the Lawrence Station aptly illustrates this point. *Bacillus prodigiosus* is a hardy, harmless variety of bacteria which is said not to occur naturally in this country.* It has a bright blood-red color, and grows luxuriantly in many situations. In order to test whether sand filters would fully destroy a hardy variety, this bacillus was added to the sewage applied to some of the experimental tanks, and the effluent examined with reference to its appearance therein. The result was that with coarse sand filters a few might be expected under ordinary conditions to pass through; while with fine sand filters, to which comparatively small quantities of sewage were applied, the removal of *Bacillus prodigiosus* appeared complete. In a practical way, therefore, we may conclude that, under the ordinary conditions of working, a few of the more hardy bacteria may pass through sand filters and appear in the effluent. On this point there is still some uncertainty, as will be shown further on in the discussion.†

* See Crookshank's Manual of Bacteriology, 3rd ed., p. 275, for morphology of *Bacillus prodigiosus.*

† The following is the general account of the experiment with *Bacillus prodigiosus*, as given by Professor William T. Sedgwick in Part II. of the Mass. Spec. Report:

From what has been said * * * it is clear that a very large percentage of the organisms of the sewage perish in the filters during intermittent filtration. The question naturally arises, Do any of the sewage organisms live to pass through, or are they all destroyed within, the filters? those that are found in the effluent being accounted for as having come from the discharge pipes, under-drains, tank floors, etc., or from the air. The hygienic importance of this question is obvious, when we consider the extreme desirability of removing all pathogenic germs from the sewage. At the same time, the difficulty of solving the problem was great in some cases, inasmuch as the kinds of bacteria likely to occur in the air, in sewage, in pipes and drains, are very similar, or perhaps even identical; and consequently the comparison of the species in the sewage and the effluents, apart from its inherent difficulty, was not likely to yield immediate results. It was, therefore, decided to experiment directly with rich cultures of a species of the bacteria foreign to the station, which could be applied in the sewage, and detected, if present, in the effluents.

For this purpose *Bacillus prodigiosus* was chosen. This species has never been observed in the sewage or effluents, and is said not to exist native in this country. It is tolerably hardy, and owing to its exceedingly rapid growth upon gelatine, and its production of a bright-red color in well-developed colonies, is comparatively easy to recognize. Luxuriant vegetations of this species were prepared either in the usual "gelatine tubes" or in the ordinary "bouillon," and after attaining the extraordinary development of which it is capable, so that a single cubic centimeter of the fluid contained millions of the individual germs, it was ready to be applied to the tanks. One or two liters of this fluid, swarming with the germs of *Bacillus prodigiosus*, were then added to the ordinary charge of sewage, for the larger tanks, and thirty cubic centimeters, or thereabouts, to that for the smaller tanks, after which the mixture was poured upon the surface. The smaller tanks of coarse mortar sand were first experimented with, and samples of the effluent were collected, beginning several hours after the application. From data obtained since that time it appears likely that these collections did not begin early enough to secure the largest discharge of germs.

The results proved conclusively, however, that *Bacillus prodigiosus* passes through these tanks of coarser sand. The number of germs discharged, as compared with the number applied, was extremely small, which indicated, so far as it went, that most of those applied had perished in the sand, precisely as those from the sewage mostly perish, during the ordinary operations of intermittent filtration. In the first experiment Tank No. 14 was used, and three tubes of gelatine already liquefied by the culture, in all some thirty cubic centimeters, were added to the sewage

By way of enforcing the statement that dejections of typhoid patients should not be allowed to pass into streams, or to be even cast on to the ground before thorough sterilization, and also to farther indicate the probable vitality of the typhoid germ, we may refer to another illustrative case, which, while often referred to in sanitary literature, may still be once more profitably reproduced by reason of the many useful deductions to be drawn from it. The case referred to is that of the outbreak of typhoid at Lausen, Switzerland, in 1872, the facts in regard to which are as follows:

Typhoid Fever at Lausen, Switzerland.

The house at A, Fig. 2, contained a number of cases of typhoid fever, during the summer of 1872, the first occurring on June 10, followed by recovery in September; the second on July 10, with recovery in October; there were also two mild cases of short duration in August. The dejections of all these cases passed into the Furlen brook, flowing near.

At about the point C there is an area of land which it was customary to irrigate each year, from the middle to the latter part of July. While the irrigation was in process this year, the public well of Lausen, at D, became so turbid and foul-tasting that many people gave up using it. This well distributes water through a wooden pipe to four public pumps, marked on Fig. 2 by dots.

At that time Lausen was a village of 780 inhabitants, living in 90 houses. Its location is on gravelly soil from 35 to 65 feet above the Ergholz brook, the elevation of which is about the elevation of the ground-water under the village. The last epidemic of typhoid fever was in 1814, when the village was occupied by soldiers; so free had it

charge. This tank had previously been fitted with side taps at different levels, in order to test the bacterial composition of the descending fluid, step by step. Whenever it was desired to use these taps, they were first sterilized by directing against them the flame of a plumber's naphtha burner. In the present experiment the fluid collected from such a tap, one foot from the surface, seven minutes after the application, contained *Bacillus prodigiosus*. The outflow from the same tap, three minutes later, also contained this species, as did that from a tap thirty inches from the surface, twelve minutes after application. It was not looked for in the effluent on this day (Nov. 21, 1888), but was found in the effluent of the 22nd on three separate trials, as well as in that from the thirty-inch side tap. It was also found in the effluent of the same tank three days after the application (November 24), and seventeen days after (December 8). It was not found at any later time, and although hundreds of examinations of the effluent of this tank, and of the sand composing it, have been made, it has never been found since. The conclusion is inevitable that it speedily died out.

The next experiment was upon a tank of similar material, Tank No. 13, on Dec. 5, 1888. As before, three tubes, or thirty cubic centimeters of a rich culture of *B. prodigiosus*, were applied in the sewage charge. On the 7th this species was found in the effluent, and also on the 8th, after which it disappeared completely. Apparently it died out even more speedily than in the first experiment.

Further experiments, made at the Lawrence Experiment Station in 1891 and 1892, and given in 23d Rept. Mass. Bd. Hlth. (1890–91), pp. 604–7, show several instances of complete and nearly complete removal of the *Bacilli typhosus*, *prodigiosus*, *coli communis*, and the bacillus of canal water. An account of these experiments was given in Eng. News, vol. xxix. p. 19 (1893).

been from typhoid that not a single case had occurred since 1865, when a few were imported from Basle.

The first case occurring in the house A, in 1872, was thought to have been imported, as the patient had been away from Lausen during the period of infection.

On August 7, 1872, 10 persons in Lausen were attacked with typhoid fever; from the 7th to the 16th, 57; from the 7th to the 28th, 100; and in September and October, 30, after which the epidemic ceased; 8 cases were fatal.

Of the 130 cases, every one had used the public water supply from

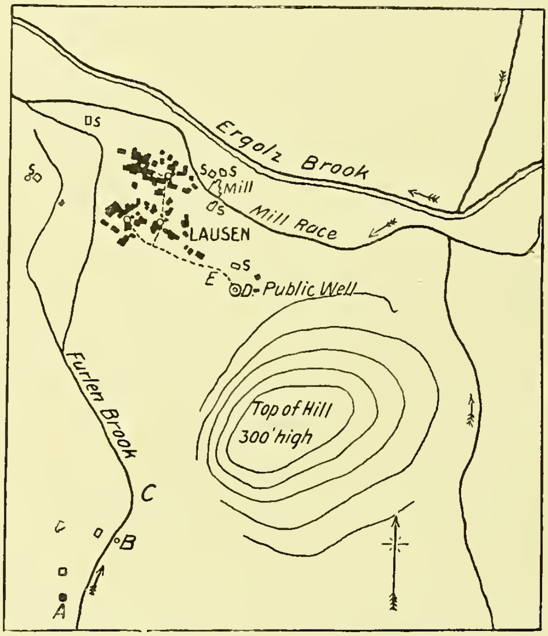


FIG. 2.—MAP OF LAUSEN, SWITZERLAND.

the well at D. Not one case occurred among those who drank other water only. Thus the 6 houses marked S are supplied from their own private wells; in them only two persons were taken sick with the fever, and it was found that they had drunk the public water when away from home.

On looking into the matter it was found that in 1862 a hole in the earth had appeared at the point B, 8 feet deep and 3 feet wide, which disclosed at its bottom a running stream, apparently fed by the Furlen brook from a point higher up. At that time the brook was led into this hole, with the result that the water all disappeared and in an hour or two streamed out at the well D, showing a connection which had

been suspected for years. On refilling the hole the brook returned to its bed.

At the investigation in 1872, after the epidemic had ceased, the hole B was reopened and a large quantity of salt thrown in; its presence at D was soon ascertained by chemical examination. A considerable quantity of flour was also added at B, but its presence could not be detected at D.

As a result of the investigation it was found that:

(1) The Furlen brook was contaminated with typhoid dejections in June, July, and August, 1872.

(2) The contaminated water was used for irrigation at C in July for about two to three weeks before the outbreak of the epidemic.

(3) This irrigation water could not have been filtered in any proper sense of the word as it was turbid and foul enough to cause many people to discontinue the use of water from the well; hence:

(4) It seems fair to conclude that the germ of typhoid passed through the ground from C to D, a distance of nearly a mile without losing its vitality.*

It may be remarked that the non-appearance of the flour at D although frequently cited as proof of the indestructibility of the germ of typhoid fever by filtration is in reality no special proof on that point, for two reasons: (1) because the pasty nature of the flour would of itself conduce to its quick retention even in coarse gravel; (2) in the case cited the typhoid germ was present in a comparatively rapid flowing stream which, apparently, entirely filled all the voids of the gravel for a considerable space, producing a case of rapid continuous filtration in which the only filtering action would be that due to a retention of suspended material; hence before it can be assumed that the typhoid germ would not under any circumstances be filtered out, it must be shown that all the voids in the filtering material are of less size than the germs.

In considering questions of this character it is necessary to keep in mind the distinction between continuous filtration and intermittent.

Typhoid Fever in Massachusetts Cities.

In Table No. 2 we have the statistics of typhoid fever in 13 cities in Massachusetts, for a series of years, both before and after the introduction of public water supplies from sources nearly all of which

* For more complete accounts of the epidemic of typhoid fever at Lausen, see

(1) The Lancet (London), July 15, 1876.
(2) Jour. Chem. Soc., June, 1876.
(3) 6th Rept. Riv. Pol. Com., p. 463.
(4) Rept. for 1873, Army Med. Dept. (English).
(5) 8th An. Rept. Mass. St. Bd. Health, p. 124.

TABLE No. 2.—THE YEARLY NUMBER OF DEATHS FROM TYPHOID FEVER PER 10,000 OF THE POPULATION IN THIRTEEN CITIES OF MASSACHUSETTS BEFORE AND AFTER THE INTRODUCTION OF PUBLIC WATER SUPPLIES.

Name.	Yearly deaths by typhoid fever per 10,000 people, 1859 to 1868.	Public water supply introduced.	Yearly deaths by typhoid fever per 10,000 people, 1878 to 1889.	Percentage deaths in the latter period to those in the former.	Population.	
					1870.	1890.
Fall River	7.78	1874	6.32	81	26,766	74,398
Springfield	9.67	1875	5.29	55	26,703	44,179
Taunton	6.12	1876	5.02	82	18,629	25,448
Northampton	10.98	1871	4.04	37	10,160	14,990
Lynn	9.06	1871	3.87	43	28,233	55,727
New Bedford	7.77	1869	3.80	49	21,320	40,733
Newton	6.57	1876	3.65	56	12,825	24,379
Malden	8.04	1870	3.54	44	7,367	23,031
Fitchburg	10.59	1872	3.16	30	11,260	22,037
Woburn	8.29	1873	2.95	36	8,560	13,499
Somerville	4.28	1867	2.95	69	14,685	40,152
Chelsea	5.97	1867	2.89	48	18,547	27,909
Waltham	8.12	1873	2.42	30	9,065	18,707

are reasonably free from sewage contamination. If we take into account the development of population in that state as illustrated by the increase in these 13 cities for the 20 years from 1870 to 1890 we cannot but admit that the showing in favor of pure water supplies as a preventive for typhoid fever is a very strong one. In Lowell and Lawrence, the public water-works of which were constructed at about the same time as those tabulated (1872 and 1875, respectively) we find that the Merrimac river, a stream known to be badly contaminated by sewage, was selected and that the typhoid rate has not decreased in either town. In Lawrence it has remained the same as previous to the introduction of the public water supply, while in Lowell the rate is considerably greater for the period following the introduction of the Merrimac river water than before.

Of the several preventable diseases, typhoid is the best known both in its etiological and pathological aspects; and in order to show its relation to public health, Table No. 3, which has been compiled from the health reports of the cities of New York, Philadelphia and Chicago, is included.*

TYPHOID FEVER AT NEW YORK, PHILADELPHIA AND CHICAGO.

From Table No. 3 we learn that the deaths from typhoid, in both Philadelphia and Chicago, are on an average double what they are in New York. The reason for this is found, it is believed, entirely in the

* This table is derived from data given in a paper, Typhoid Fever in Chicago. By Prof. Wm. T. Sedgwick and Allen Hazen. Eng. News, vol. xxvii., pp. 399, 400 (April 21, 1892); also reprinted in pamphlet form. Reference to this paper may be made for a large amount of statistical information in regard to typhoid fever in its relation to polluted water supplies.

TABLE NO. 3.—STATISTICS OF TYPHOID FEVER IN RELATION TO TOTAL POPULATION AND DEATHS FROM ALL CAUSES IN NEW YORK, PHILADELPHIA AND CHICAGO, 1870 TO 1891, INCLUSIVE.

Year.	New York.					Philadelphia.					Chicago.					Year.
	Total population.	Deaths from all causes.	Typhoid fever.			Total population.	Deaths from all causes.	Typhoid fever.			Total population.	Deaths from all causes.	Typhoid fever.			
			Total deaths.	Per cent. of all deaths.	Deaths per 10,000 inhabitants.			Total deaths.	Per cent. of all deaths.	Deaths per 10,000 inhabitants.			Total deaths.	Per cent. of all deaths.	Deaths per 10,000 inhabitants.	
1870	943,300	27,175	422	1.55	4.47	674.022	15,317	409	2.67	6.06	298,000	7,323	268	3.66	9.00	1870
1871	955,921	26,976	251	0.93	2.62	700,000	15,485	313	2.02	4.47	334,270	6,976	272	3.90	8.14	1871
1872	968,710	32.647	386	1.18	3.98	725,000	18,987	369	1.94	5.09	367,396	10.156	524	5.16	14.26	1872
1873	981,671	29,084	313	1.07	3.19	750,000	15,224	364	2.39	4.85	380,000	9,557	272	2.85	7.15	1873
1874	1,030,607	28,727	305	1.06	2.96	775,000	15,238	461	3.02	5.95	395,000	8,075	211	2.61	5.34	1874
1875	1,044,396	30,709	376	1.22	3.60	800,000	17,805	420	2.36	5.25	407,060	7,899	207	2.62	5 09	1875
1876	1,075,532	29,152	325	1.11	3.02	825,000	18,892	761	4.03	9.22	420,000	8,573	168	1.96	4.00	1876
1877	1,107,597	26,203	343	1.31	3.10	850.856	16,004	542	3.39	6.37	439,776	8,026	159	1.98	3 61	1877
1878	1,140,617	27,008	321	1.19	2.81	876.118	15,743	404	2.57	4.61	450,000	7,422	146	1.97	3.24	1878
1879	1,174,621	28,342	268	0.94	2.28	901,380*	15,473	344	2.22	3.82	475,000	8,614	208	2.41	4.38	1879
1880	1,209,268	31,937	372	1.16	3.08	846,980*	17,711	498	2.81	5 88	503,298	10,462	171	1.63	3.40	1880
1881	1,246,011	38,624	594	1.54	4.77	868,600*	19,515	654	3.30	7.43	540,000	13,874	568	4.10	10.52	1881
1882	1,283,870	37,924	516	1.36	4.02	886,539*	20.059	650	3.24	7.33	560,639	13,234	462	3.49	8.24	1882
1883	1,322,880	34,011	,625	1.84	4 72	907,041*	20.076	579	2.88	6 38	580,000	11,555	361	3.12	6.22	1883
1884	1,363,075	35,034	476	1.36	3.49	927,995	19,999	662	3.31	7.13	630,000	12,471	354	2.84	5.62	1884
1885	1,404,401	35,682	405	1.13	2.88	949,432	21.392	610	2.85	6.42	665,000	12,474	496	3.98	7.46	1885
1886	1,447,166	37.351	433	1 16	2.99	971,363	20,005	618	3.09	6.36	704,000	13,699	483	3.52	6.86	1886
1887	1,491.137	38,933	421	1.08	2.82	993,801	21,719	621	2.86	6.25	760,000	15,409	381	2.47	5.01	1887
1888	1.536,444	40,175	364	0.90	2.37	1,016,758	20,372	785	3.85	7.72	830,000	15,772	375	2.38	4 52	1888
1889	1,583,120	39,679	397	1.00	2.51	1,040,245	20,536	736	3.59	7.07	1,100,000†	16,946	453	2.67	4.70	1889
1890	1,631,232	40,103	352	0.88	2.16	1,046,964	21,732	666	3.07	6.36	1,200,000	21,869	1,008	4.61	8.40	1890
1891	1,700,000	43,634	384	0.88	2.26	1,092,168	23,367	6.4	2.93	6.27	1,200,000	27,754	1,997	7.19	16.64	1891
Averages.	....	......	...	....	3.19	....	......	...	....	6.20	....	......	.....	....	6.90	Averages.

* These figures are here given as they stand in Phil. Health Rept. for 1890, p. 154.

† Large additions to territory in 1889.

relative degree of pollution in the water supplies of these cities. On this point a considerable amount of evidence is submitted in the chapters following.

The effect of introducing into a city a public water supply uncontaminated by sewage has been almost universally to materially reduce the death rate from typhoid. In order to illustrate this point we may refer to Tables Nos. 2 and 4.

Typhoid Fever at Rochester, N. Y.

Table No. 4 presents the deaths from typhoid in the city of Rochester, N. Y., by months, from 1870 to 1891, inclusive. Previous to the year 1873 this city, which then had a population of nearly 74,000, was entirely without a public water supply. Water for domestic purposes was drawn from shallow wells, which in the course of time had become badly polluted through the operation of soil saturation. The extent of the pollution may be appreciated by considering the results of a series of analyses of the water of 40 wells made in 1877, when it was found that the average amount of sodium chloride per U. S. gallon of the well water was 16.78 grains. The normal sodium chloride of the region, as determined from an unpolluted well, was 1.36 grains per

Table No. 4.—Statistics of Typhoid Fever at Rochester, N. Y., from 1870 to 1891, inclusive.

Year.	Months.													Population.	No. of deaths per 10,000 population.
	January.	February.	March.	April,	May.	June.	July.	August.	September.	October.	November.	December.	Totals.		
1870. ...	2	3	3	1	2	1	5	2	12	14	6	3	54	62,386*	8.65
1871.....	3	2	2	1	0	3	3	2	2	7	2	3	30	66,253	4.53
1872.....	6	1	2	2	1	1	4	8	10	17	8	10	70	70,120	9.99
1873.....	5	6	4	1	4	2	1	5	5	12	6	10	61	73,987	8.24
1874....	1	1	0	1	1	2	4	5	4	11	5	6	41	77,854	5.27
1875.....	5	4	2	2	3	2	3	2	3	11	4	3	44	81,722*	5.39
1876	3	3	3	2	2	1	1	2	2	6	4	2	31	83,250	3.72
1877.....	2	0	0	2	1	0	0	4	5	5	6	2	27	84,780	3.19
1878.....	1	1	0	1	4	1	1	3	4	0	0	1	17	86,310	1.97
1879. ...	1	0	1	3	1	1	0	2	1	1	4	2	17	87,840	1.93
1880.....	1	1	1	1	0	0	1	5	0	7	3	1	21	89,366*	2.35
1881.....	2	0	4	1	0	1	0	2	5	6	4	1	26	91,860	2.82
1882.....	3	2	0	3	3	1	0	0	4	5	4	5	30	94,650	3.17
1883....	8	1	2	1	4	1	0	4	4	6	5	3	39	97,960	3.98
1884.....	3	0	2	3	1	1	2	2	4	7	9	9	43	101,710	4.23
1885.....	8	2	1	2	0	0	1	2	5	8	2	1	32	105,950	3.02
1886....	1	1	1	3	2	2	1	3	7	5	3	4	33	110,450	2.99
1887.....	3	2	2	1	0	0	2	2	9	9	5	3	38	115,150	3.30
1888....	5	4	1	2	3	1	1	10	14	9	2	2	54	120,150	4.49
1889.....	1	3	1	0	0	1	5	4	6	8	3	7	39	126,400	3.09
1890. ..	3	2	3	2	2	1	6	3	6	7	3	5	43	133,896*	3.21
1891.....	1	3	2	3	5	3	5	2	8	6	4	9	51	142,500	3.58
Totals.	68	42	37	38	39	26	46	74	120	167	92	92	841	....	......

* Official population.

gallon. At the same time the average amount of sodium chloride in samples of sewage collected from nine of the principal sewers of the city was found to be 5.26 grains per gallon. In some of the badly polluted wells free ammonia was found to the amount of 1.5 grains per gallon, and albuminoid ammonia 0.5 grain per gallon.*

With a water supply of this character it was inevitable that sickness of all kinds would rapidly increase and we accordingly find the typhoid rate 10 per 10,000 inhabitants in 1872.

In January, 1874, a partial water supply was introduced from the Genesee river, which, while not suitable for domestic purposes, was still of value by reason of furnishing a means of flushing sewers and assisting in maintaining the general cleanliness of the town.

In January, 1876, a domestic supply from Hemlock lake was introduced. Its use rapidly extended among all classes of citizens, until in 1892 at least 95 per cent. of the total population used the water from Hemlock lake for all domestic purposes. From such general use of an uncontaminated water resulted a permanent material lowering of the typhoid rate, as indicated in Table No. 4.

The detailed statistics of typhoid at Rochester show that in 1878 to 1880, the death rate from the disease was only 2.05 per 10,000 of the population. During these years the use of Hemlock lake water was extending very rapidly, and by the end of 1880 the use of the uncontaminated water had become nearly universal in the localities most affected by typhoid fever. A marked rise in the typhoid death rate began in 1881, which has continued permanent to the present time, averaging 3.51 per 10,000 for the period 1882 to 1891. The reason for this increase is apparently as follows:

The city of Rochester is situated upon the Genesee river, a few miles south from the point where the river empties into Lake Ontario. The river now receives the crude sewage of over one-half the population, and in the near future, when constructions now under way are completed, will receive it all, or the sewage of a population of say 140,000. The total fall in the river in its course through the city is about 266 feet, the major portion of this being included in the three falls known as the Upper, Lower, and Middle falls of the Genesee. The balance of the total is included in several reaches of rapids. A short distance below the Lower fall the river has found the approximate level of Lake Ontario, and there changes its character from that of a shallow stream with alternating falls and rapids to that of a stream with sluggish flow in a deep, wide channel. From this point to the lake, a distance of a trifle less than 6 miles, the channel is from about 300 to 500

*Report to the Board of Health and the Executive Board of the city of Rochester. N. Y., in regard to the chemical examination of samples of water from suspected wells. By Professor S. A. Lattimore. In An. Rept. Ex. Bd., City of Rochester for 1877.

feet in width, with an average depth for the greater portion of the distance of about 24 to 25 feet.

The river rises in Potter county, Pennsylvania, and flows north across the state of New York. A considerable portion of its drainage area is characterized by steep slopes, and the stream, in consequence, responds quickly to a rainfall. The ordinary flood flow is perhaps 35,000 cubic feet per second, while its minimum flow is as low as 130 cubic feet per second. Hence during the time of minimum flow the velocity in the deep water below the Lower fall is very slight; at times it does not exceed 1 mile in 24 hours. Into such a body of at times nearly still water the sewage of over one-half of the population is now discharged, although before reaching the deep water it has passed over the Middle and Lower falls and the intervening rapids. (A small portion has further passed over the Upper fall.)

The river carries a considerable amount of silt in suspension, and in times of low water a very thorough sedimentation takes place in the upper reaches of the still water. During high water the velocity is sufficient to sweep the precipitated matter out into the lake, as is proven (1) by the channel maintaining a nearly uniform depth from year to year; and (2) by the formation of a bar off the mouth at the lake.

About 1880 a number of large hotels were constructed on the lake beach not far from the mouth of the Genesee river. Numerous cottages were erected and there soon gathered about and near the river's mouth a considerable summer population, consisting almost entirely of citizens of Rochester. On Sundays and holidays it is no uncommon thing for from 25,000 to 30,000 people to visit the lake beach. Drinking water is supplied through pipes which lead a short distance into the lake, and through which at times the sewage polluted water of the Genesee river, mixed with lake water, is drawn.

With the information at hand there seems reason to infer that the growth of the summer resorts at Lake Ontario and the consequent drinking by a large number of citizens of a seriously polluted water, has directly contributed to nearly double the typhoid rate in the city of Rochester. The influence of the out-go of population to the lake is forcibly shown by the increase in number of deaths from typhoid fever in the months of May, June, and July in 1889, 1890, and 1891, these months being usually free from that disease. As the matter stands a warm May is followed by an increase in the typhoid death rate, either in the latter part of the month or in the following month of June.

We have here the case of a city which, properly enough, has spent several million dollars in procuring an uncontaminated water supply but in which a lack of clear views on sanitary questions has led to a condition of affairs which in a considerable degree negatives the result

of the large expenditure. The conditions at the present time, while the Genesee river receives only one-half the sewage of the city, are alarming enough, in view of the statistics here presented; when the river receives the entire sewage of the city, a still further increase in the typhoid rate in summer may be expected.

The Fundamental Proposition.

From the consideration of a large number of cases similar to the foregoing we derive the conclusion that crude sewage should never be discharged into any body of water used as a water supply at any point within the influence of the sewage. This statement may be considered the fundamental proposition of modern sewage disposal.

In the following chapters we shall discuss the various cognate questions requiring consideration in order to determine how the indispensable purification may be best attained in any given case.

CHAPTER II.

THE INFECTIOUS DISEASES OF ANIMALS.

The subject of water-borne communicable diseases of human beings may be considered as standing closely allied to that of the communicable infectious diseases of animals; and while this important branch of the general subject has not, as a whole, received the attention which it deserves, we still have accumulated in the last two or three decades a considerable body of information, some of which will be referred to here.

Definition of Terms.

In this discussion the word infection will be taken as opposed to contagion in the sense that contagious diseases are only communicated by immediate personal contact, as by touching or by breathing the breath. Infectious diseases will be considered as those which may be communicated through considerable space, as typhoid fever, the germ of which may be, as already pointed out, borne long distances in water. Under these definitions it is apparent that some diseases are both infectious and contagious (tuberculosis, for example), though such are for convenience here referred to as infectious only, the present discussion having no reference to their communicability from the contagious point of view.

It has already been stated that some of the infectious diseases are communicable from men to animals, and from animals to men; and the opinion is rapidly gaining ground that the animal diseases communicable to human beings have a greater influence over health and life than has been generally supposed.*

Important Inter-communicable Diseases.

Among the water-borne communicable diseases of animals which have either been proven also common to man, or are strongly suspected of being so, may be mentioned, as of great importance, glanders, hog cholera, Texas fever, anthrax, tuberculosis, and actinomycosis. All of these have been widely prevalent among animals in this country in recent years, and if in any way communicable to man, every opportunity for their dissemination by running water has been offered. There are

* 1st Rept. Beau. An. Ind. (1884), p. 68.

a number of other infectious diseases of animals, probably a score in all, but with the exception of Texas fever, none of such diseases are regarded as having originated in this country.*

Glanders.

The first of the important diseases, glanders, is a specific infectious disease especially peculiar to horses, but also capable of transmission to men, sheep, dogs, cats, and some of the rodents; whether hogs are susceptible to it is yet uncertain, but horned cattle and domestic fowls are stated to be proof against it.

The seat of the disease is either (1) the lymphatic glands, (2) the mucous membrane of the nasal and respiratory tract, or (3) the lungs and spleen. The definite germ causing it is *Bacillus mallei*,† discovered by Loffler and Schutz in 1882. It classifies with the specific diseases caused by a germ (Saprophytes), which when planted in the tissues of an animal body, developes therein, but which exists, naturally, as a spore outside the animal body.

Although in one form of glanders the discharge from certain ulcers may be a source of infection, the germs are transmitted chiefly by the nasal discharge, by scattering the germs promiscuously in feed-boxes, watering-troughs and the like. They may gain access to the system by way of the digestive tract, when the discharge is present in drinking-water or food. So far as is known, this disease is never air-borne.‡

Hog Cholera.

Hog cholera, or swine plague, is an infectious disease of hogs, resembling in many particulars both typhoid fever and dysentery in man. The disease is apparently distinct from typhoid fever as indicated by generic differences in the micro-organisms producing the two diseases, though they have the common characteristic of each, being the cause of ulceration of the region in and about the intestine, typhoid fever appearing in the lower part of the small intestine, and hog cholera chiefly in the upper part of the large intestine.

Hog cholera is perhaps more closely allied to dysentery in man, than to typhoid fever; but our knowledge of hog cholera is still too limited to enable us to say definitely that its bacilli can produce dysentery in man.

The transmission of the bacillus of hog cholera by water is, however, a matter of more certainty, and it may be taken as settled that it

* Contagious Animal Diseases, Dr. Ezra M. Hunt. 1st Rept. Beau. An. Ind. (1884), pp. 437–443.
† Crookshank, Manual of Bacteriology, 3d ed., p. 325.
‡ Glanders, C. A. Cary, Bul. No. 25 (June, 1891), S. Dak. Ag. Col. and Ex. Sta.

is a water-borne disease, and it is in this connection that we are chiefly interested in considering it here. On this point a large amount of evidence is presented by the recent writers,* who conclude that streams are perhaps the most potent agents in its distribution. Laboratory experiments show that the bacilli may not only remain alive in water for four months, but they may even multiply when in water contaminated with sewage or other organic matter. Assuming that they will survive the various adverse influences likely to be met with in natural water only two months, and it still appears possible that an original planting at the head of the longest river in the country might infect herds throughout its whole course.

Experiments have been made by the biologists of the Bureau of Animal Industry upon the vitality of the bacilli of hog cholera and their resistance to various germicides determined. The general conclusion may be drawn from the experiments that they are somewhat tenacious of life, although certain reagents properly applied easily destroy them.†

Texas Fever.

Exact information relative to the etiology of Texas fever is difficult to obtain. The biologists of the Bureau of Animal Industry affirm on the one hand that it is essentially a blood disease in which all the symptoms and lesions are referable to the destruction of red corpuscles; ‡ while on the other hand, according to Paul Paquin, the biologist of the Missouri Agricultural College Experiment Station, the germs are found outside of the blood corpuscles in the liver and spleen, under conditions apparently indicating their presence in the blood as an incident of the disease and not its chief cause. Paquin considers that the ordinary source of infection is by ingestion, the same as for glanders and hog cholera, and water contaminated by the excrements of infected cattle is mentioned as a prolific method of dissemination.§ The biologists of the Bureau of Animal Industry in their last report have affirmed that cattle ticks are chiefly concerned in spreading the disease from one animal to another. For the present we may look upon Texas fever as probably one of the water-borne communicable diseases of cattle, although the evidence, so fully establishing it, is not yet at hand.

* Swine Plague, its Causes, Nature and Prevention. By Frank S. Billings. Bul. of Ag. Ex. Sta. of Neb., vol. ii., No. 4 (June 30, 1888). The Influence of Running Streams upon the Extension of Swine Plague, pp. 31–32.

Hog Cholera, its History, Nature and Treatment. Rep. Beau. An. Ind. (1889). Relation of Hog Cholera to the Public Health, pp. 120–122. Prevention of Hog Cholera pp. 123–133.

† Hog Cholera (*loc. cit.*) pp. 75–103.

‡ 1st Report of the Secretary of Agriculture (1889), p. 91. 2d Report (1890), pp. 105–110.

§ Texas Fever, by Paul Paquin. Bul. No. 11, Mo. Ag. Col. Ex. Sta. (May, 1890).

Dr. Billings asserts positively that Texas fever "is an infectious disease of a very malignant type." He points out that it is indigenous, or at any rate apparently confined to the moist, hot regions of the South, and corresponds closely with yellow fever in man which is found in the same localities.*

ANTHRAX.

Anthrax is the best known of all the infectious diseases which are intercommunicable between animals and man. Its specific germ, *Bacillus anthrax,* presents in its life-history nearly every phase of bacterial development. It presents distinctive features which prevent its confusion with other forms, and inasmuch as its morphological and biological characteristics have been completely worked out, it serves as an excellent type for gaining acquaintance with the methods employed in studying micro-organisms.† When occurring in animals the disease is known as Charbon, splenic fever, or simply as anthrax, while in man it has been variously denominated wool-sorters' disease and malignant pustule. In both man and animals ingestion is considered a chief source of infection, although there are other sources, as with most of these intercommunicable infectious diseases. Flowing water is mentioned as one of the methods of dissemination.

A number of years ago there was an outbreak of wool-sorters' disease among the operatives of a large woollen factory at Bradford, England. At the same time the disease appeared among cattle feeding in a meadow through which flowed the stream receiving the washings from the factory where the wool sorters were suffering from the disease.‡

There is a modified variety of the disease among cattle, known as black-leg.§

TUBERCULOSIS.

Tuberculosis has also received a large amount of attention since the new views in relation to germs, as the specific cause of infectious diseases, grew up. Its existence in cattle as well as human beings has been known for many years, but it is only in the last decade that the evidence has been accumulated which enables the positive assertion to be made, not only that bovine tuberculosis is communicable to man, but that human tuberculosis is communicable to a number of the lower animals, as cattle, dogs, cats, and fowls.

* Frank S. Billings, The Relations of Animal Diseases to the Public Health (1884), p. 130.

† Crookshank, Manual of Bacteriology, 3rd ed., pp. 315–325.

‡ For some of the more important points in relation to Anthrax, see Report on Anthrax in 6th An. Rept. Prov. Bd. Health of Ontario (1888).

§ Black-leg, by Paul Paquin, Bul. No. 12, Mo. Ag. Col. Ex. Sta. (June, 1890).

Actinomycosis.

Actinomycosis has during several years past been observed in different parts of the country, especially at the Chicago stock yards, where a large number of cattle are assembled. The disease has long been known in England under various local designations, but it is only since the comprehensive studies of Crookshank (1887) that the intercorrelation of the various forms has been fully pointed out.

In cattle the disease appears first as a swelling in the lower jaw, subsequently spreading to the upper jaw and neighboring parts. In man the symptoms are sometimes those of chronic bronchitis, accompanied by fetid expectorations. It also invades the bones, causing caries.

Paquin states* that some cases of actinomycosis in man, like cases of glanders, are not recognized as such. A case in Southern Missouri, which local physicians designated by various names, was probably contracted by drinking at the same trough with an ox which was suffering from actinomycosis at the lower maxillary. The lesions in the man were in one of the maxillary articulations.

The cause of actinomycosis is a fungus closely resembling *Cladothrix*, which may be detected, in the fresh discharge of a bovine tumor, with the naked eye. In man the appearance of the fungus is somewhat different, but inoculation experiments have proven the interrelation.†

In discussing the preceding communicable diseases they have been considered as communicable chiefly by ingestion, that is, by passing into the digestive tract in food or drink, and gaining access to the physical economy through some of the delicate membranes with which they come in contact. Tuberculosis is frequently communicable in this way, but it is further conveyed from one animal to another, from one person to another, or from persons to animals and *vice versa*, by breathing the breath.‡ The method by which actinomycosis is transmitted is, like Texas fever, not yet well settled, although drinking-water and food appear as the more usual sources of infection.

Typhoid Fever in Animals.

The foregoing six diseases include the leading diseases of animals which, by reason of prevailing extensively in recent years in this country, are of most importance in the present connection. They, however, do not exhaust the list of diseases common to animals which may be

* Actinomycosis, The Bacteriological World, vol. i., No. 1 (June, 1891).

† Actinomyces, Crookshank, Manual of Bacteriology, 3rd ed., p. 379, and following. Also see recent reports of several of the State Boards of Health.

‡ Tuberculosis, Chas. H. Fernald, Bul. No. 3 (Jan., 1889), Hatch Ex. Sta of the Mass. Ag. Col.

considered as water-borne, and which are possibly in some degree intercommunicable. Investigations have been made abroad by Klein and other bacteriologists in reference to the possibility of infecting animals with true typhoid, and in this country Dr. Victor C. Vaughan, of the University of Michigan, has succeeded in producing typhoid in dogs and cats by inoculation.* There are in addition to the foregoing some reasons for supposing that typhoid fever is common among animals, in so modified a form as to be generally unnoticed, although the germs from their dejecta may produce the true typhoid in human subjects. A few words about the theory of the propagation of the disease, in addition to what has been said in Chapter I., will make this plain.

The specific microbe of typhoid is a bacillus which forms spores within itself, as already referred to on page 7; these spore-holding bacilli may be expelled in myriads in the fæces. The resistant power of the spores has been also referred to on page 7, and the further statement may be made, that under favorable circumstances the spores are preserved for an unknown period. There can be no typhoid fever without either the bacillus or the spore, and the fact that this disease has many a time attacked travellers in regions uninhabitable by human beings, but in which various wild animals abound, may be fairly taken as indicating the prevalence of the disease among the animals there, with the existence of the spore in their dejecta the same as in the stools of human beings. In a number of well-attested cases travellers have been attacked after drinking from water-holes to which wild animals also came for drinking-water in times of drought. Again cases have occurred in civilized regions where the most exhaustive inquiry failed to reveal a pre-existent case. If we admit the agency of animals as carriers of the germs, the explanation of very many such cases is greatly simplified.

Blyth's Theory of Typhoid.

According to Blyth, however, the most reasonable theory is that the cause of typhoid fever is a vegetable parasite capable of existing, propagating its kind, and completing its cycle of existence independent of an animal body; probably its normal existence is, like glanders, that of a Saprophyte, or plant living upon dead organic matter. Hence its endemic prevalence in places where its presence cannot be traced to a pre-existing case, and hence the mysterious isolated outbreaks which from time to time occur.†

* 16th An. Rept. Mich. St. Bd. Health (1889), p. xlvi.
† Blyth, A Manual of Public Health (1890), p. 504.

The Entozoic Diseases.

The entozoic diseases, while invasive rather than infectious, are also common to men and animals; they are of interest in a discussion of sewage disposal because the advocates of the numerous precipitation processes have at one time somewhat vigorously insisted that sewage farms must inevitably become centres of distribution for entozoic germs.*

At present the argument against irrigation derived from the assumed distribution of entozoic germs has little weight, and Mr. Slater, whose book is the recent authoritative exposition of the views of the English precipitationists, in his chapter on irrigation does not mention it at all.†

The Tape or Intestinal Worms.

The entozoa are of interest in the present connection, not only from their parasitic life in men and animals, but because a common method by which they gain access to the human economy is from drinking-water. They are characterized by a remarkable development of the reproductive system. A common form, *Tænia solium*, the tape worm, has neither mouth nor stomach, the so-called head being merely an organ for attachment, the numerous segments of the body each containing within itself the necessary generative apparatus to enable it fertilize and mature its own numerous eggs. The relations of *Tænia* to cystic entozoa which inhabit the muscles and glands of hogs and sheep has been shown to be very close; they are in fact the same form modified by the environment. Other forms of entozoa, among which *Ascarus lumbricoides*, the common intestinal worm, may be considered typical, infest the intestines of almost every vertebrated animal, their eggs passing readily from one to the other through the medium of drinking-water.‡

An Iowa Case.

M. Stalker gives an interesting account of a severe outbreak of disease, in the latter part of the summer of 1890, among the domestic animals on a farm in Iowa, in which horses, cattle, and sheep were all affected in the same way.§ The local symptoms, largely confined to the throat, were a swelling and partial paralysis of the walls of the upper

* Tidy, The Treatment of Sewage, No. 94, Van Nostrand's Sci. Series, pp. 101–103.

† J. W. Slater, Sewage Treatment, Purification, and Utilization (1888).

‡ Carpenter, The Microscope and its Revelations, 6th ed. (1881), p. 693.

§ Some Observations on Contaminated Water Supply for Live Stock, M. Stalker, *Bul.* No. 13, (May, 1891), Iowa Ag. Ex. Station.

air-passages, accompanied by painful and difficult breathing. The animals attacked uniformly died after an illness of about two days. The extraordinary nature of the case, animals of so many different species all suffering from the same disease and all dying of it, led to a somewhat close study of the surroundings, with the result of ascertaining that the animals affected had all obtained drinking-water from a small creek which ran in a ravine through the farm. The dry weather for several months previous to the attack had so reduced the flow of the stream that water was found only in pools along its bed. A few animals on the same farm which did not have access to the creek, but which were watered from a well were, although in contact with the sick, entirely unaffected. On inquiry it appeared that earlier in the summer chicken cholera had prevailed among the fowls and hog cholera among the swine, and that a considerable number of dead chickens and hogs were thrown down the steep bluffs of the ravine into the bed of the stream. On other farms in the neighborhood it was customary to dispose of dead animals in the same way, and inquiry further showed that on no less than four other farms situated on the banks of this stream, animals had died showing symptoms identical with those on the farm first investigated.

Mr. Stalker also states another case where contaminated water was distinctly proven as the cause of large mortality among cattle running on the open prairie. An animal dead from anthrax had been drawn into a basin which later filled with rain-water and furnished a drinking-place for about 1,000 cattle on the adjacent range. The result was that about ten per cent. of all the animals having access died from anthrax. In the language of Mr. Stalker:

> The teachings of these object lessons are sufficiently obvious. These animals are endowed with organizations not unlike our own, and the manifest laws of being and of health can no more be violated with impunity by them, than by ourselves.

Need for More Definite Information.

The foregoing remarks on the infectious diseases of animals are a very inadequate presentation of the subject as it stands at the present day. In Europe the literature has already become exceedingly voluminous, while in this country there is also too much of it to enable one to present other than a skeleton in a brief chapter like the present. It is hoped enough has been said to indicate that the subject is of importance in connection with the general question of pollution of streams, and the purification of the sewage of any large town where extensive stock yards are located. Certainly the allowing of the drainage from stock yards and abattoirs to contaminate streams

which are the sources of public water supplies cannot be considered in touch with the best recent thought on public sanitation.*

This discussion must be further taken as indicating that a sewage-polluted stream is not a safe source of drinking water for horses, cattle, and other domestic animals.

Per contra we may say that a stream to which animals suffering from any of the intercommunicable diseases have access is not a safe source of drinking-water for human beings, though the fact pointed out by Dr. Billings, that "man has far greater receptivity to the contagious (infectious) diseases of animals than they have to those of man" may be considered as indicating less danger to animals than to human beings from the use of drinking-water polluted by the excrements of either.

* Professor J. H. Long states in his report on Chemical Investigations of the Water Supplies of Illinois, 1888–89, that, in the summer of 1886, the sewage of the Chicago Stock Yards amounted to about 7,000,000 gallons daily, and gave then by several analyses in parts per 100,000 the following:

Free ammonia,	4.20
Albuminoid ammonia,	0.64
Oxygen consumed,	20.80

It is also stated that later tests show a great improvement in the character of the Stock Yard effluent, due to the fact that it has been found commercially profitable to remove many of the contaminating matters for use as fertilizers and for other purposes. (Professor Long's report, page 9.)

CHAPTER III.

ON THE POLLUTION OF STREAMS.

The State of Massachusetts Leads in the Study of Stream Pollution.

The history of stream pollution and the discussion of measures for its abatement have been confined in this country, until recently, almost entirely to the Reports of the Massachusetts State Board of Health. Something has indeed been done in several of the other states, but to Massachusetts must be assigned the credit of not only first taking up the subject systematically but of materially advancing accurate knowledge of the subject.

In making the preceding statement the authors have not overlooked the work done in several of the other states, as for instance, Maine, Connecticut, New York, New Jersey, Pennsylvania, Minnesota, and Illinois. A large proportion of the work in the other states is, however, considerably later in point of time than that in Massachusetts, and some of it has been modelled after the Massachusetts work as published from year to year in the Annual Reports of the State Board of Health. The credit of a systematic beginning therefore properly belongs to Massachusetts.

Amount of Stream Pollution Investigation.

The amount of systematic work and discussion of the same have now grown to such proportions as to render any adequate presentation of the tabulated results impossible in the limits of a single chapter in a book of this character, and about all that will be attempted here is to give a brief account of the work actually accomplished, in the preparation of which the various reports will be used in some sort as a syllabus. A complete knowledge of stream pollution as it stands in this country to-day can only be obtained by a study of the original reports.

We will begin by reviewing the work done in Massachusetts, in regard to which it may be remarked that a portion of the information in the earlier reports, by reason of the recent developments, is somewhat out of date; it has nevertheless been deemed proper, in view of

the historical importance of the Massachusetts work, to give a brief synopsis of all that has been done in that state in the way of studies of stream pollution and cognate questions.

The Massachusetts Work.

On April 6, 1872, the Massachusetts legislature directed the State Board of Health to "consider the general subject of the disposition of the sewage of towns and cities" and "report to the next legislature their views, with such information as they can obtain upon the subject from our own or other lands." This order of the Massachusetts legistture may be fixed upon as the beginning of accurate information in reference to sewerage, sewage disposal, and the pollution of streams in this country.* In compliance with the order the Board employed Professor Wm. Ripley Nichols, who, in conjunction with Dr. George Derby, Secretary of the Board, presented a report of 112 pages, which may be found in the Fourth Annual Report of the Board.

After defining the terms sewer, sewerage, and sewage, the Report discusses at some length the following questions:

(1) The Dry Earth System.

(2) The Water Carriage System.

(3) The Ventilation of House Drains.

(4) Sewage from other sources (*i.e.*, other than human wastes, kitchen drainage, etc.).

(5) Other forms of Refuse not Removable by Sewers (as, for instance, swill, ashes, meat and vegetable refuse, etc.).

(6) Sewage.

(7) Sewers.

(8) Sewers now in Use in Massachusetts.

(9) Outlets of Sewers in Massachusetts.

(10) On the Treatment of Sewage (including value of the sewage, lime process, phosphate process, intermittent filtration, and sewage irrigation).

(11) On the Treatment and Utilization of Sewage in Massachusetts, (including tabulated statements of the results of analyses of sewage of Boston and Worcester).

(12) The Effect of Sewage and Manufacturing Refuse on Running Streams (including examinations of a number of streams, namely, Mill brook, Blackstone river, and Merrimac river). Also condition of certain English rivers.

(13) Alleged Self-Purification of Running Streams.

* This may be considered a broad statement in view of the systematic design of several large sewerage systems, notably that of Chicago several years previous to 1872. The statement is intended more especially in reference to the design of sewerage systems with regard to systematic disposal other than into large bodies of water.

(14) The Water Supply of Towns.
(15) Lakes and " Great Ponds."
(16) Great Ponds are Public Property.

Under heads (2) and (4) the report states that while drains have been in use for thousands of years it is only in the present century that they have been used as carriers of human excrement. The other waste substances passing into sewers are the liquid slops from washing and cooking, the washings and scrapings of hides, the washings of slaughter-houses and stables, chemicals used in the preparation of leather and morocco, chemicals used in cotton factories and print works, the fluid wastes of rendering establishments and of soap factories, and the liquid wastes of other manufacturing establishments of every description.

Under (7) the report states that " Sewers may be used (1) for the exclusive removal of excremental and waste fluids ; (2) for the removal of rainfall ; (3) for the removal of superfluous water in the soil." " There are those who strongly advocate the separation of the first two from each other. The rainfall to the river, the sewage to the soil is an alliterative saying which has had great currency in England. It however involves the construction of a complete double set of sewers in every case, and it sacrifices the advantage of occasional flushing and the complete washing out of these conduits by occasional storms. Our best engineers do not advise this separation, except to provide storm-water overflows as a measure of economy."

Under (9) the report states : " We believe that, in the present state of human knowledge and experience, no better receptacle than the ocean can be found, provided the sewage is delivered where deep currents can disperse it so that it can be no more seen, and can prevent its deposit in the settling-basins of docks and the mud flats of estuaries."

Under (11) the report discusses the manurial value of excrement and deduces a value for the sewage of Boston of perhaps one cent per net ton.

Under (12) tabulated analyses of the waters of the streams studied is given, together with brief statement of some of the difficulties in the way of maintaining the purity of streams receiving manufacturing refuse.

In the Fifth Annual Report of the Board the discussion is continued by Professor Nichols with special reference to the condition of certain rivers in the state, the inquiry being prosecuted more especially in reference to " the increasing joint use of watercourses for sewers and as a source of supply for domestic use." The rivers selected for extended examination were the Merrimac, Blackstone, Sudbury, Concord, and Charles.

The report begins with a discussion of the sources of pollution of the Merrimac river and presents in detail statements of population

and number of operatives of some of the manufacturing towns, with statistics of the annual use of polluting substances, such as oil, starch, flour, madder, copperas, alum, sumac, sulphuric acid, bark, soda ash, and soap. The character of the river bed and the condition of the river are also considered. Extended tables of analyses are given and the relative effect of oxidation, deposition, and dilution in assisting purification discussed.

The studies of the Blackstone river, begun in the previous year, are continued and tables given of analyses of series of samples of water taken at different points. These together with the tables of analyses of the waters of the Charles, Sudbury, and Concord rivers, and a single examination of water from the Neponset river conclude the examination of river waters in the Fifth Report.

Professor Nichols then takes up the discussion of (1) rivers as a source of supply, in which chapter the various arguments pro and con. are clearly stated; (2) the present condition of the water-supply of certain cities in Massachusetts, the water-supplies discussed being the Cochituate and Mystic of Boston, the Merrimac river at Lowell and Lawrence—the water-works of which latter was at that time in process of construction—and the Charles river, which was already in use at Waltham and had been at various times proposed for a number of other towns. Tables of analyses of the various water-supplies are presented.

These two reports in the Fourth and Fifth Annual Reports of the Massachusetts State Board of Health are thus noted somewhat in detail, not only because of the valuable discussions of the several subjects considered, but because of their historical value as the starting-point of a definite knowledge of river pollution and the cognate questions in this country. The task of making a beginning could hardly have fallen into more capable hands than those of the late Professor Wm. Ripley Nichols.

In continuation of the work thus begun we find in chapter 192 of the Acts and Resolves passed by the General Court of Massachusetts in 1875 an act to provide for an investigation of the question of the use of running streams as common sewers in relation to the public health. By its terms the State Board of Health is directed to investigate by themselves, or by agents employed by them, the correct method of drainage and sewerage of the cities and towns of the commonwealth, especially with regard to the pollution of rivers, estuaries, and ponds by such drainage or sewerage.

The investigations undertaken under this act were divided into three heads and each assigned to a specialist for study and discussion as follows:

(1) The pollution of rivers, with general observations on water sup-

plies and sewerage, James P. Kirkwood, M. Am. Soc. C. E., the necessary chemical analyses being made by Professor Nichols.

(2) The water supply, drainage, and sewerage of the state from a sanitary point of view, Frederick Winsor, M. D.

(3) The disposal of sewage, Chas. F. Folsom, M. D., Secretary of the Board.

These several reports, which appear in the Seventh Annual Report of the Board, make 385 octavo pages of printed matter and present nearly every phase of the subject, and may at the present day be taken with slight modifications as a pertinent treatise with special reference to the conditions obtaining in this country.

In Part II. of Mr. Kirkwood's report is given a brief account of the kinds of chemicals used in the various manufacturing processes, as prepared by L. B. Ward, M. Am. Soc. C. E., chiefly from the English reports, with reference to the differences in practice in this country. This part of the report includes notices of the processes of the following: The manufacture of woollen and cotton goods ; bleaching operations; linen and jute manufacture with the bleaching of the same; jute dyeing; silk manufacture; paper manufacture; metal manufactures, including iron works and rolling mills, and iron and steel wire and galvanizing works, together with brass foundries and electro-plate works. The report also includes a chapter on poisoned water and its limits, with experiments upon fish with acids, metallic salts, special chemicals, and furnace ashes, this latter information adapted entirely from the English reports.

Detailed statistics of all existing sources of pollution on the several rivers examined are given in this portion of the report.

In a report of 100 pages Dr. Frederick Winsor discusses the questions relating to water-supply, drainage, and sewerage in Massachusetts from the sanitary point of view.

In the section devoted to the Disposal of Sewage, by Dr. C. F. Folsom, the following are the several heads discussed:

(1) The effect of filth on health.

(2) The influence of sewer-gases on health.

(3) Water contaminated by sewage.

(4) Experience in England.

(5) The sewage question in England.

(6) Substitutes for the water-carriage system.

(7) Experience in France.

(8) Experience in Germany.

(9) Experience in Holland.

(10) Experience in other countries.

(11) Processes for purifying sewage—including filtration, intermittent downward filtration, precipitation by lime, aluminia, superphosphate,

sulphite of lime and magnesia, the A. B. C. process, metallic salts, Suvern's system, and Lenk's process.

(12) Irrigation, including sub-soil irrigation, surface irrigation, the mode of distributing sewage, location of sewage farms, amount of land necessary, the effect of climate, theory of the purification of sewage, the effluent from sewage farms, alleged ill effects and the cost of irrigation.

(13) Methods of disposing of sewage in the various English and Continental towns, including Manchester, Leeds, Birmingham, Coventry, Edinburgh, West Derby, Crewe, Romford, Croydon, Bedford, Tunbridge Wells, Leamington, Merthyr Tydfil, Paris (sewage farm at Gennevilliers), and Danzig.

(14) The waste of sewage.

(15) The conditions of sewage farming.

In the summary following the several reports the Board makes the following recommendations :

(I.) That no city or town shall be allowed to discharge sewage into any water-course or pond without first purifying it according to the best process at present known, which is irrigation ; provided that this regulation does not apply to the discharge from sewers already built, unless water-supplies be thereby polluted ; and provided also that any intended discharge of sewage can be shown to be at such a point that no nuisance will arise from it.

(II.) That no sewage of any kind, whether purified or not, be allowed to enter any pond or stream used for domestic purposes.

(III.) That each water-basin should be regarded by itself in the preparations of plans of sewerage and water-supplies.

(IV.) That accurate topographical surveys always be made of all towns before introducing water-supplies or sewers.

(V.) That steps should be taken, by special legislation, based upon investigations and recommendations of experts, to meet cases of serious annoyance arising from defective arrangements for the disposal of sewage.

(VI.) That irrigation be adopted, at first experimentally, in those places where some process of purification of sewage is necessary ; and that cities and towns be authorized by law to take such land as may be necessary for that purpose.

(VII.) That every city or town of over 4,000 inhabitants be required by law to appoint a Board of Health, the members of which shall be required not to hold any other offices in the government of their city or town.

In the Eighth Annual Report (1877) the discussion of stream pollution and sewage disposal is continued by the Secretary of the Board. The stream selected for this year's work was the Nashua river, which was not only polluted at many points, but from being situated in two States was considered to illustrate most of the important features of such an investigation.

The topics discussed under this head are : Area and population of the river basin ; water supply and sewerage of the towns in the basin ; statistics of the sources of pollution in detail ; including the specific kinds of pollution from woollen mills, paper mills, cotton mills, comb manufactories, tanneries, etc. ; the purification of polluted streams ;

pollution of the Nashua river; some pollution unavoidable; and disposal of sewage in the Nashua basin.

From the Report it appears that the area drained by the Nashua river in Massachusetts is 457 square miles; in New Hampshire 87 miles. The average population for the portion in Massachusetts was found to be 106.5 per square mile.

None of the towns in the Nashua basin had sewerage systems at the date of the Report, although a few surface-water drains had been built in Fitchburg, Clinton, and Leominster, the three chief towns in the portion of the river basin in Massachusetts. The chief sources of pollution were therefore found to be the wastes from manufactories. The following included all in this basin in Massachusetts at that time:

	Number of manufactories.	Hands employed.
Woollen mills	14	1,265
Shoddy mills	2	6
Cotton mills	22	2,478
Paper mills	20	437
Edge-tool and machine works	6	350
Comb manufactories	9	330
Tanneries	4	180
Chair and tub shops	3	245
Leather-board mills	5	94
Flour mills	2	14
Gas works	2	6
Linen mill	1	22
Wood-pulp mill	1	6
Cotton and Shoddy mill	1	10
Totals	92	5,443

The Nashua river flows from Massachusetts into New Hampshire, joining the Merrimac river at the city of Nashua in the latter State; the Merrimac itself passes into Massachusetts in a few miles flow.

The result of the examination was to lead to the conclusion, as stated in the Report, that the pollution of the Nashua river, while mostly from manufacturing wastes, was still altogether too serious to permit of the use of the stream at any point, except at its extreme head-waters, as the source of public water supplies.

In the portion of the Eighth Report referring to the disposal of sewage, the following are the heads discussed: Experiments in Massachusetts; progress elsewhere; sewage disposal at Glasgow; the Liernur system; brief references to disposal at Coventry, Leeds, Hille's process, and sewage precipitates generally; dry removal; opinions of experts as deduced from results of sanitary conference held in

1876 under the auspices of the Society of Arts; English government statistics published in March, 1876, including purification by overflow of sewage on land; filtration, precipitation and filtration, cost of precipitation, cost of irrigation, cost of Barking farm, cost of Cheltenham farm, cost of Bedford farm, cost of dry removal, cost of no removal of sewage, and conclusion of the English Local Government Board; experience in Germany, Austria, and France; objections to irrigation below Paris; sewage of Paris; irrigation with sewage of Paris; proposed intercepting sewer for Paris and deep sea outlet; experiments on precipitation at Paris; present condition of the question at Paris, objections, etc.; some objections to sewage irrigation considered; effects on health of bad drainage; contaminated water; the purist theory; contaminated air and soil; oxidation of sewage; filth not safe and specific poison theory; illustrative cases of disease from poisoned air at Croydon, Fort Cumberland, and Uppingham school; illustrative cases of disease from polluted water at Eagley and Bolton, England, and Lausen, Switzerland; * yellow fever and filth: dysentery and fever from filth; earth-closets; and the prevention of filth diseases.

E. S. Chesbrough, M. Am. Soc. C. E., also discusses in the Eighth Annual Report the subject of Sewerage, its Advantages and Disadvantages, Construction and Maintenance.

In the Ninth Annual Report, Sewerage and the Pollution of Streams is further discussed by the Board, the investigations for the year having been made with special reference to the basins of the Hoosac and Housatonic rivers. Statistics in detail of the sources of pollution in the river basins examined are given, same as in the previous reports, and at the conclusion the Board presents a draft of A Bill to Prevent the Pollution of Streams, and for Other Purposes. In concluding this portion of the report the Board submit the following:

Recommendations.

There are a few points to be borne in mind with reference to water-supply, drainage of houses, and sewerage, which have been suggested by the examinations of the Board in this State, and may properly be summarized here:—

1. The privy system, so common throughout the State, by which filth is stored up to pollute the air, soil, and water, near dwellings, should be in all cases abolished.

2. Cesspools, unless with extraordinary precautions as to ventilation and prevention of pollution of soil and air, are little better, and should be given up for something less objectionable as soon as practicable.

3. Wells cannot be depended on for supplies of wholesome water, unless they are thoroughly guarded from sources of surface and subsoil pollution. Some of the foulest well-water examined by the Board has been clear, sparkling, and of not unpleasant taste.

4. Where wells have already been polluted, and it is not practicable to dig new

* This is a good account of the famous case where typhoid germs are proven to have passed through a mile of gravel. Account illustrated by map. Also see Chapter I.

deep wells remote from sources of contamination, or to introduce pure public water supplies, the storage of rain-water, properly filtered, is a satisfactory method of procedure.

5. In small towns where public water supplies have not been introduced, and, indeed, wherever water-closets are not used, some method of frequent removal and disinfection with earth or ashes, should be adopted in place of privies, by which it should be impossible for the filth to soak into the soil or escape into the air. Cemented vaults are not always to be depended upon, as their walls crack from frost or through settling of the ground; and they thus sometimes become sources of pollution of wells, besides contaminating the air. Nor is the fact of a privy being on a downward slope from the well a sufficient safeguard; for even then the direction of the subsoil drainage may be toward the well.

6. Earth-closets, *with proper care*, may be satisfactorily adopted. But the earth, after having been once used, should be placed upon the land, not stored within doors and dried, to be again used; for, in the process of drying, there are emanations from it which are, perhaps, not less dangerous from the fact of their being imperceptible by the unaided senses, or through chemical examination. With earth-closets, a plan similar to that in use at the Pittsfield Hospital* may be well used for the chamber slops; and the kitchen waste may be utilized (with the chamber slops, too, if desired) in the manner used by Mr. Field and Col. Waring. . . . Less intricate methods are used in scattered dwellings, but with the effect of having the slop-water absorbed by the ground and taken up by vegetation so far from the house as not to involve a nuisance or danger to health.

7. Where water supplies, water-closets, etc., are introduced, sewers should follow immediately, in most kinds of soil; cesspools should not be used, unless with extraordinary precautions. But with a few hundred feet square of lawn, the irrigation system by agricultural drain-pipes is to be recommended, whereby the filth is at once taken up by the roots of grass. In all cases, of course, with or without cesspools, there should be thorough ventilation of the system of house-drainage, with disconnection from the main-outlet drain by means of either a ventilating pipe or rain-water spout between the sewer-trap and the house, and whose openings at the top should be only at points remote from windows and chimney-tops.

On the whole, a thoroughly satisfactory arrangement of this kind, if properly looked after, is in many respects to be preferred to connecting with public sewers.

8. While the water-carriage system is the least offensive to a refined people, the least costly in the end if on a large scale, and, when well managed, the least objectionable from a sanitary point of view, it should be remembered: (1), that in the case of towns and cities of moderate size its introduction involves the outlay of a large capital; (2), that the connections between houses and sewers can be made free from danger-bringing elements only with great care, and that usually from a want of such care they are often productive of a certain amount of harm—a danger often very great, especially to children and delicate persons, since the possibility of the continuous ill effect on the system of a slight poison is not often recognized, and as few people can be induced to believe that anything is a poison from which they cannot see immediate and striking ill results; (3), that the outlets of sewers, except near large bodies of water, generally involve a great deal of difficulty, and often of serious nuisance, from the fact that there is at present no really satisfactory way of disposing of the sewage, while a properly arranged system of frequent dry removal is not attended with especial danger to health, and may at any time be changed for better methods without involving any great pecuniary loss.

When sewers are built, or sewerage systems adopted, the work should be planned and carried out only by the best available talent; for badly constructed sewers are in many respects worse than none; and their proper arrangement and maintenance involve an amount of knowledge, skill, and experience, which are found only among men of unusual ability, who have had special opportunities for preparing themselves for their work.

Whichever of the three great disinfectants and destroyers of filth is used—namely, *a sufficient quantity* of earth, water, or air and sunlight—the essential process is the same: the effete matters are converted by oxidation and by chemical

*Described in an article on Cottage Hospitals, pp. 83–95, 9th Ann. Rept.

combination into products that are finally both harmless and inoffensive. In all three the oxygen is the most important agent, and burning, or oxidation, is the essential process. The most offensive gases, however, to a certain extent when in the earth, and to a less degree in the water, are absorbed mechanically; in the earth, too, the foul-smelling sulphuretted hydrogen unites with the iron found in most soils, forming an inert and inoffensive compound. But in all three, unless the amount of filth is proportionately very small, there are certain gases escaping, and what are called emanations—possibly, too, disease "germs"—often so minute or diluted as not to be appreciable to our senses. It is the part of prudence, therefore, to have any and all of these processes reasonably remote from dwellings, and within certain limits to destroy all filth by oxidation, sewage irrigation, etc., with as little delay as may be necessary.

All of these points seem of such importance to the Board, that, in their opinion, no city or town shall be allowed to embark upon costly schemes of water-supply and sewerage without having the benefit of advice from somebody who has had experience in such matters. There has therefore been inserted, in the draft of the law which precedes, a section providing that all such plans must be approved by the Rivers Pollution Commission. The matter of local drainage is also one involving great danger to the public health if not properly regulated; and provisions for that, too, have been made in the bill.

In 1879 the State Board of Health of Massachusetts was succeeded by the State Board of Health, Lunacy, and Charity, and in the first report of that Board (1880) the investigations as begun by the previous Board are continued, by a study of the basin of the Westfield river, which with a further preliminary examination of the Merrimack river concludes the special work of pollution on streams for the year 1879.

Professor Nichols gives in this report an account of a stream polluted by a large quantity of sulphuric acid discharged into it by the burning of a chemical works. This case is of considerable value as illustrating how seemingly great amounts of contaminating material may under favorable conditions be easily lost sight of in large volumes of water.

The Second Report of the State Board of Health, Lunacy, and Charity, contains an investigation of the pollution of the Deerfield and Miller rivers as made by W. E. Hoyt, C. E., with the statistics given in form similar to that of previous years.

The Third Report contains in Appendix B, (1) a report on the Worcester sewage and the Blackstone river, by Drs. Folsom and Wolcott and Joseph P. Davis, M. Am. Soc. C. E.; and (2) a report on the same subject by Col. Geo. E. Waring, Jr., M. Inst. C. E., the latter presented on behalf of the town of Milbury, situated on the Blackstone river below Worcester and alleged to be suffering from the nuisance caused by the sewage pollution in the stream.*

Appendix C contains extracts from the Report on the First Metropolitan Drainage Commission as presented to the Massachusetts Legislature, Jan. 9, 1882.

* For further references to these two Reports see Chapter XXVII. on sewage disposal at Worcester, Mass.

The next work on pollution of streams in Massachusetts is in the Nineteenth Annual Report of the State Board of Health (1888), where are given tables of analyses of the waters of several of the streams examined in previous years. An outline of the proposed experiments on sewage purification at Lawrence is also given.

In the Twentieth and Twenty-first Reports questions of pollution are incidentally discussed from the standpoint of the recent views under the head of advice to cities and towns in relation to water supply and sewerage.

In the Special Report, Part I., and in the Twenty-second and Twenty-third Annual Reports, may be found the best exposition of many of the questions arising in connection with stream pollution that has yet been made.

In the Chapter on the Examination of Rivers in the Special Report, the pollution of the Blackstone river is first considered. This river is stated to be, by reason of receiving the sewage of the city of Worcester, the most polluted stream in Massachusetts. For several miles below Worcester the stream was found not only very offensive at times, but too dirty for use in the manufacture of light colored cloths.

The report gives a series of analyses of (1) the unpolluted water of the streams which unite to form the Blackstone above Worcester; (2) samples taken at Quinsigamond village about one mile below the point where the Worcester sewage enters the Blackstone; (3) at Uxbridge 17 miles below, and (4) at Millville 24 miles below. Table No. 4 A gives the means of analyses made in 1887, 1888 and a portion of 1889, and is from data in the Special Report.

TABLE No. 4 A.—MEANS OF ANALYSES OF WATER OF BLACKSTONE RIVER AT THE POINTS INDICATED, AS MADE IN 1887, 1888 AND 1889.

(Parts per 100,000.)

Locality.	Number of analyses in series.	Color.	Residue on evaporation.			Ammonia.		Chlorine.	Nitrogen as	
			Total.	Loss on ignition.	Fixed.	Free.	Albuminoid.		Nitrates.	Nitrites.
Lynde Brook reservoir	23	0.25	2.98	0.91	2.07	.0040	.0162	0.14	.0062	.0001
Tatnuck Brook reservoir	23	0.19	2.43	0.86	1.57	.0009	.0155	0.12	.0038	.0001
River below Quinsigamond village	24	0.70	23.83	5.66	18.17	.2160	.1218	1.19	.0315	.0027
River at Uxbridge	24	0.40	6.67	1.48	5.19	.1011	.0286	0.65	.0292	.0009
River at Millville	24	0.39	5.06	1.26	3.80	.0455	.0253	0.46	.0211	.0005

At Millville, the lowest point at which the samples were taken, the drainage area is about four times as great as at Quinsigamond village,

while the population is only 34 per cent. greater. A very considerable purification takes place in the flow down the river by reason of dilution, independent of any purification resulting from other causes. The dilution is nearly sufficient to account for all the purification indicated by the chemical analyses.

In Table No. 4 B we have the averages of a similar series of analyses made from June, 1889, to December, 1890, and given in the Twenty-second Annual Report.

TABLE NO. 4 B.—MEANS OF ANALYSES OF WATER OF BLACKSTONE RIVER AT THE POINTS INDICATED, AS MADE IN 1889 AND 1890.

(Parts per 100,000.)

Locality.	Number of analyses in series.	Color.	Residue on evaporation.		Ammonia.				Chlorine.	Nitrogen as		Hardness.
						Albuminoid.						
			Total.	Loss on ignition.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.	
Lynde Brook reservoir.....	19*	0.22	3.07	1.15	.0028	.0149	.0121	.0028	0.15	.0062	.0001	0.9
Tatnuck Brook reservoir....	19*	0.19	2.74	1.24	.0005	.0153	.0115	.0038	0.13	.0056	.0000	0.9
River above Worcester sewage disposal works........	19*	0.84	9.97	3.04	.2452	.1135	.0615	.0520	1.10	.0295	.0018	2.82
River below Worcester sewage disposal works........	6†	0.95	11.43	3.20	.2860	.1510	.0787	.0723	1.44	.0345	.0022	3.72
River at Uxbridge..........	20‡	0.27	8.27	1.69	.1131	.0242	.0167	.0077	0.67	.0302	.0007	2.88
River at Millville...........	20‡	0.38	6.81	2.31	.0544	.0231	.0180	.0051	0.46	.0216	.0003	2.25

* Six analyses included in the mean total residue and five in the loss on ignition.
† These analyses were all made in 1890 after the opening of the sewage disposal works.
‡ Seven analyses included in the mean total residue and six in the loss on ignition.
The means for total residue and loss on ignition included in Table No. 4 B are all of analyses made after opening of Worcester sewage disposal works in 1890.

In considering the results of the analyses embodied in Table No. 4 B it may be remembered that the Worcester disposal works were put in operation June 25, 1890.

The Worcester sewage is mostly discharged into Mill brook, which flows into the Blackstone river at Quinsigamond village. The watershed of Mill brook is about 12.5 square miles with an average daily flow of about a million gallons per square mile, or the average daily volume of brook water is something like 12,500,000 gallons. In dry weather the average daily flow is less than this. The sewage proper amounted to about 5,000,000 gallons per day in 1892.

At present the main intercepting sewer extends only from the new precipitation works, which are situated about one mile south of Quinsigamond village, to the lower end of the Mill brook channel, where it intercepts the sewage after dilution with brook water to the extent indicated in the foregoing.

During the time covered by the analyses in Table No. 4 B, only

about 3,000,000 gallons of the polluted brook water were treated at the disposal works, the balance of the untreated flow of Mill brook entering the river as formerly.

The effect of the treatment of the 3,000,000 gallons daily is indicated by the third and fourth series of Table No. 4 B.*

The results of recent studies of the pollution of the Charles, Chicopee, Concord, Connecticut, Deerfield, Hoosac, Housatonic, Ipswich, Merrimack, Millers, Nashua, Neponset, Shawsheen, Stony Brook, Taunton, Ten Mile, and Westfield rivers, are given in the Special Report. The Twenty-second Annual Report also contains the continuation of the study of a number of the streams.

In the Twenty-third Annual Report the results of studies of the Blackstone are continued to include the year 1891; the same is true of the Merrimack and Taunton rivers. In addition advantage was taken of an unusually dry season to make special studies of the Blackstone, Quaboag, Merrimack, Nashua and Neponset rivers. The Report states:

> Nearly all of the examinations show an increasing pollution of the streams as compared with previous years. This is caused not only by the fact that the summer and autumn of 1891 were drier than for several years before, but also by an unusually rapid increase in population and manufactures during these years, little being done by the towns and manufacturers to keep the larger streams from being polluted.—(p. 256.)

Other Massachusetts Reports of value are (1) the Report of Commission Appointed to Consider a General System of Drainage for the Valleys of the Mystic, Blackstone and Charles rivers (1886); and (2) the Report of the State Board of Health upon the sewerage of the Mystic and Charles River Valleys (1889). Both of these reports should be read by whoever wishes to fully consider the literature of Sewage Disposal in the United States.

Maine.

In Maine a few chemical analyses of river waters used as public supplies have been made by the State Board of Health in the last few years, the results of which may be found in the Annual Reports of the State Board.

Connecticut.

In Connecticut the General Assembly, by an Act approved March 24, 1886, made it incumbent upon the State Board of Health to "investigate and ascertain so far as practicable all facts in relation to the pollution of streams and natural waters of this state by artificial causes,

* For further in regard to pollution of the Blackstone, see Chapter XXVII.

which in their judgment may be necessary to determine the sanitary and economic effects of such pollution."

The work authorized by this act was put in charge of Professor S. W. Williston, of Yale College, who submitted a preliminary report in the Tenth Annual Report of the State Board (1888). According to Professor Williston, this enactment grew out of a conviction on the part of those acquainted with the rapidly growing pollution of the streams of Connecticut that the time had arrived when state jurisdiction was imperatively needed. Many of the streams are already in or approaching a state of excessive pollution. The growth of manufacturing interests, and the decrease of the agricultural population, has been steady and general in Connecticut for some years. The manufacturing towns and cities have thus increased rapidly; many of them showing 50 per cent. or more in the last decade. This has produced a twofold result upon the streams; not only are the manufacturing wastes added, but the population by compacting in towns is brought into the most favorable condition for discharging sewage and other human waste products directly into the rivers.

The chapter on Manufacturing Processes and Refuse in Professor Williston's Report gives in brief space the essential facts in relation to pollution from the ordinary manufacturing processes, and it is accordingly included here as a useful contribution to the recent American literature of rivers pollution.

Manufacturing Processes and Refuse.

BRASS MANUFACTURES.

As is well known, the various brass manufactories form the chief industry of the Naugatuck valley, an industry for which not only the chief towns on the river are noted, but also for which the State itself is justly celebrated throughout America. These brass works, notwithstanding their extent, are in reality productive of little harm to the river in a sanitary sense, though they have long since rendered the water of the stream wholly unfit for fish, the chief waste, sulphate of copper, being the most poisonous of any substance known to this form of life. Their refuse, aside from the sewage of their operatives, is almost wholly acids and oils, with a certain considerable quantity of the metals themselves dissolved by the action of the acids.

The refuse or waste materials differ somewhat in character, but not much, according to the product of the various mills. Some of the manufactories produce only the sheet or bar brass from the copper and zinc; others are engaged wholly in the production of the various metal goods from the alloy, while others manufacture both the alloy and the goods. Of the rolling mills proper there are a half dozen or more, located in Torrington, Thomaston, Waterbury, Seymour, and Ansonia, and all of them are on a more or less extensive scale, employing about four-fifths of all the operatives engaged in the brass industries in the Naugatuck valley.

In the rolling mills, the acids, chiefly sulphuric, are used almost wholly for the removal of the oxidized scales on the surface of the metal after annealing. The metal, in the process of rolling, as is well known, becomes hard and brittle and requires repeated heating in order to render it ductile. After having been thus heated, the tarnished surface is again rendered clean and shining by immersion in

diluted acid, a process technically called "pickling." The acid for this purpose is diluted in a large vat with six to twelve times its quantity of water, and is constantly kept renewed by the addition of acid as its strength is weakened. This pickling vat may be emptied and renewed daily, weekly, or at longer intervals, depending upon the different usages, and the different amounts of metal treated in it. In no case, however, am I aware of the recovery of any part of the acid in the metal salts, except in copper mills, where the copper crystals, precipitated from the saturated solution, are removed and thrown into the furnace to be again reduced to the metal state. After the metal has been allowed to remain in the pickling vat for a few minutes, it is removed and placed in another vat of running clean water, to remove the residue of acid. It is thus seen that all or nearly all of the acids employed reach the stream, carrying with them copper and zinc in solution. How much copper and zinc is thus lost I cannot say, but, from analysis, I believe that more than one-half of the acid becomes saturated, so that the amount actually going into the stream is at least thirty per cent. greater than the amount of acid used.

Almost the only other, and the worst, element of contamination from the rolling mills, is that caused by the oils used. The brass that is cast into bars, either for future rolling, or for use as such in other manufacturing purposes, requires the use of oil in the moulds, but this, it is unnecessary to state, is all consumed. In the process of rolling, however, lard, fish, and whale oils in about equal proportions, are applied to the surface of the metal and the rollers. Some little of this oil, it is true, finds its way through and is consumed by the fire in the process of annealing; but the great pressure of the rolls, it is readily understood, squeezes back this and causes it to flow off, for the greater part, into a trough or depression below, whence it is carried off by a stream of constantly flowing water. Very little of the mineral oils is used in rolling, but chiefly for lubrication on bearings. My reports will not show accurately the amount of oils that are used, for, in some of the manufactories where I am pretty confident they must be employed to a greater or less extent, no reports were given of them. Several of the largest manufactories on the river did, however, give complete reports, from which it is evident that lard oil is not the one chiefly used, but also whale and fish oils, as well as large quantities of the mineral oils. The report of one large firm will give a pretty clear idea of the amount used for the rolling mills. In this manufactory, for each one thousand pounds of metal treated or manufactured one gallon of "fish and mineral" oils was used and fifteen pounds of acid. Of course the lighter mineral oils are the ones least likely to get into the water and the ones least injurious.

The only other refuse from the rolling mills, aside from the sewage of the operatives, is derived from the cinders, scoriæ, and other matter containing fragments of the metal which it is desired to save. This material, after having been crushed, is washed by water and the metals separated and again used.

Much the larger amount of brass used is composed of copper and zinc in the proportion of about six to four; where the alloy is desired of a more granular or brittle character to adapt it for turning, rather than for ductility, a small part (two or three per cent.) of lead is added.

In the larger number of the manufactories the alloy is cast or turned, or otherwise formed into the various objects for which the metal is used, and here necessarily they undergo a different treatment, but one not essentially different so far as refuse is concerned, save in the use of oil. In most of these the acid is used to give some desired finish to the goods, and not merely to clean the surface. Sulphuric acid is still used in by far the larger quantity, but muriatic and nitric acids are also used in different ways and in different combinations to produce different effects. The process is technically called "dipping," and the acid is used in full strength in small kettles kept at a boiling temperature. Before being dipped, the goods are treated with a solution of caustic soda to remove whatever grease may be adhering to them. After dipping they are washed in running water and polished. The dipping vats are kept at the required strength and the contents changed from time to time (several months before being wholly changed). The combination of these acids, their proper degrees of strength, and the proper methods of using them, require a certain degree of technical skill on the part of the worker. The metal salts are not recovered in this process, or, if so, are treated as refuse, so that the

acids all practically find their way into the stream, together with a considerable quantity of the metals.

One hundred pounds of sulphuric acid used in the pickling baths require for saturation :

64.3 pounds of copper, producing 254 pounds of blue vitriol [$CuO+H_2SO_4=CuSO_4+H_2O$].
66.3 pounds of zinc, producing 292 pounds of white vitriol [$ZnO+H_2SO_4=ZnSO_4+H_2O$].

One hundred pounds of the same acid used in the hot dipping baths would require :

32.1 pounds of copper, producing 127 pounds of blue vitriol [$Cu+2(H_2SO_4)=CuSO_4+SO_2+2(H_2O)$].
33.2 pounds of zinc, producing 146.4 pounds of white vitriol [$ZnSO_4+7H_2O$].

Considerable quantities of soap are reported from the latter class of manufactories, used for wire drawing and lubricating metals in press operations.

In the polishing of brass and iron considerable quantities of oil and grease are used, which are afterward removed by potash in different forms, or other alkalies.

In all the brass manufactories, save the rolling mills proper, considerable quantities of cyanide of potash and ammonia are reported. These are used in electro-metallurgical processes, and all are wasted, together with some fatty matters taken up by the alkali. Goods to be electroplated are first treated with the alkali to remove what greasy matters may be adhering to the metal, and are then subjected to a dilute bath of acid to remove the oxides from the surface. They are then placed in a solution of the cyanide of potash, which acts as a carrier or agent in the deposition of the metal by the galvanic current.

Cyanide of potash, as is well known, is a virulent poison, and there is a sufficient quantity employed annually in the Naugatuck valley to destroy all the inhabitants of the United States, yet it is doubtful whether its contaminating influence is very great. The waste solution is more or less neutralized by acids and diluted in the drain-pipes that carry them off.

The amount of aqua ammonia reported does not differ much in the various manufactories; from two-thirds as much in weight, as of the cyanide of potash, to an equal quantity are given.

IRON MANUFACTURE.

In the manufacture of iron, almost the only waste of importance comes from the pickling baths, used to give a clean non-oxidized surface to the metal. These pickling vats, as I saw them in one of the largest iron manufactories in the State, were elongated tanks holding several hundred gallons of dilute sulphuric acid, kept at a boiling temperature. The iron, in the shape of bars or long plates, was brought in, in bundles, by suspended pulleys and immersed for a few minutes in the first vat, after which it was carried to a second similar vat and likewise allowed to remain for a short time. It is next dipped into a vat of water to wash off the superfluous acid, and is then dipped into a fourth vat containing a heated solution of lime to neutralize the remaining acid.

The common practice is to add fresh acid to these vats from time to time during the day, as it is needed, and then to empty them all at the close of the day's work. A sample which I was kindly permitted to take at the Stanley works, of New Britain, from one of these pickling tubs a little before the contents were to be turned into the stream, gave the following, as stated by Professor Smith :

"The 'bath solution' contains 5.66 per cent. of sulphuric acid, calculated as such, of which there is sufficient iron to unite with 87 per cent., leaving but 13 per cent. of the sulphuric acid in the free condition ; or, .79 per cent. is the amount of free acid that the solution contains."

It is thus seen that four-fifths or more of the acid enters the stream as sulphate

of iron (copperas). For every ton of acid thus used, nine hundred pounds of iron are taken up in solution, producing four thousand pounds of copperas, to which is to be added four hundred pounds of free acid.

Tinning is a process that is often applied to iron goods, and especially to pins. It is done by boiling the goods to be whitened in a solution of cream of tartar with block tin or "tin crystals" for two or three hours. Practically all the waste here is the cream of tartar alone. In the manufacture of pins there is but little other waste; the pins are made by machines which complete them ready to whiten; after whitening they are stuck in papers. Hooks and eyes are whitened in the same way, or are covered with japan, a varnish composed of asphaltum, linseed oil, and turpentine, of which there is little or no waste.

In the manufacture of metal buttons and similar goods, another source of waste, aside from that due to the ordinary use of the acids, is the japan varnish removed from tin plate. The articles are boiled in a solution of caustic soda, and the latter is washed off and carried into the stream together with the saponified varnish. Small amounts of stannate of soda probably go with the soda. In the baking to which the varnished articles are previously subjected the turpentine of the varnish is, of course, dissipated. This waste, however, cannot be very important. In a firm employing two hundred hands, not more than eight pounds of the alkali used daily were reported, and there consequently could not be a very large quantity of the varnish removed.

In the polishing of the metals, as has already been said, considerable quantities of oil and grease are used, which are afterward removed by potash or other alkalies.

PAPER MANUFACTURE.

There are numerous paper mills on the streams examined, and I have been unable to obtain a full knowledge of the waste products of the very various raw materials used. In many of the smaller manufactories, especially on the Hockanum, heavy binder's boards are made, and as there is no bleaching nor much cleaning of the raw materials, there is little refuse. In others where the coarser papers are manufactured, and where jute, gunny sacking, old paper, and colored rags are used, the organic waste may be as great or even greater than in those where the higher qualities of writing paper are produced.

In the manufacture of paper from rags, the first process that the material undergoes is prolonged boiling under pressure in a solution of lime, by which the fibre is freed from the glutinous and other matter. Caustic soda may be used for this purpose, especially for the lower grades of paper, but in the mills in Connecticut lime is used either alone, or, for colored rags, with a slight addition of the soda. This solution of lime, after use, with all its impurities, is turned into the stream, and the rags are subjected to long and thorough washing. It is seen that almost if not quite all of the lime thus gets into the stream; certainly but a very small part can remain in the fibre after several hours washing in running water. From ten to fifteen pounds are used to every hundred pounds of rags, and the extractive matter dissolved out by it, together with more or less of the fibre itself washed away, must add materially to the waste. The next process in the production of white or light-colored papers is bleaching. The material used for this purpose is called chloride of lime, but is really a combination of the chloride and hypochlorite, and even in the best qualities rarely has more than thirty-five per cent. of chlorine, the effective agent. The residuum of non-soluble parts is turned into the stream and the clear solution is applied to the pulp. To set free the chlorine, large quantities (a third or a half as much as the bleaching powders) of alum (or, in some places, sulphuric acid) is added to the solution. The pulp is allowed to remain in the solution for some time, when it is removed and very thoroughly washed, and the spent solution is discharged into the river. Again here it is seen that, besides the alum, nearly the whole quantity of the bleaching powder finds its way into the stream, either as lime, chloride of lime undissolved, or other chlorides, chlorine gas dissolved in the water, or hydrochloric acid. All this bleaching waste is highly injurious to fishes.

The refuse from this class of mills, though containing not a little organic matter from the filth, grease, etc., of the rags, cannot convey many germs, as they must be destroyed in the boiling processes, except such as are in the dust and refuse separated in the preliminary sorting out of the rags. The fatty acids, furthermore, are converted into insoluble lime soaps. A large part of the material discharged is lime, a substance that can hardly be said to contaminate the water, especially in New England, where the rivers are deficient in this mineral matter. For every million pounds of fine writing-paper manufactured, from three to four hundred thousand pounds of solid refuse matter are discharged into the river. According to the British reports on Rivers Pollution, from fine white rags there is about fifteen per cent. refuse; from colored rags, twenty-five per cent.; from esparto, forty; and from straw, fifty per cent.*

WOOLLEN MANUFACTURE.

On the rivers examined, the woollen manufactories are chiefly confined to the Hockanum. On the Naugatuck there are but few that manufacture from the raw material. In former years the woollen manufacture of this stream was much more important than it is at present. During the last year, even, one of the principal mills, that at Beacon Falls, has suspended indefinitely its operations, throwing out of employ some three hundred operatives. There is probably no class of manufactories in the State that pollute the streams more extensively, in proportion to their number, than these, their waste consisting, as it does, chiefly of organic material.

"Wool is always accompanied with other secretions, which issue from the skin along with it and lubricate it, rendering it more or less 'yolky' and giving it its peculiar and characteristic odor. These secretions differ enormously in amount between the different breeds, and vary greatly in character. Here it is sufficient to say that besides the oil that accompanies all wool, there is a complicated mixture of several chemical substances called together 'yolk' or gum (or sometimes 'suint,' the French name, German 'Fetterschweiss' and 'Wollschweiss'), and which constitutes a large percentage of the unwashed merino wool. In extreme cases, and with certain fine-wooled breeds, these secretions constitute upward of sixty per cent. of the unwashed fleece, diminishing in quantity as the fibres becomes coarser and the staple longer, and as the wool passes from the carding to the combing varieties, reaching its minimum in certain coarse-wooled native breeds. This 'yolk is chemically a sort of natural soap, and is more or less soluble in water. In certain merino breeds it is bred for, and thus its quantity has been relatively increased, and, when abundant, dirt and dust are more apt to cling to the wool,' thus diminishing still further the percentage of actual wool fibre." (Professor W. H. Brewer, Report of the National Acad. of Sciences, 1885, p. 84.)

As is stated by Professor Brewer above, the composition of this "yolk" or "suint" is very complicated; in an analysis appended to his report, no less than thirty different chemical compounds are enumerated.

"It is the common practice with sheep growers in most countries before shearing to wash the sheep in running water of natural temperature. The yolk is partly soluble in cold water (more in hot), and if the washing is thorough, a part also of the oil and attached dirt is removed, the oil being somewhat soluble in a solution of the yolk, or else it and other dirt are mechanically removed with the soapy emulsion. No matter how poorly this washing by the wool-grower may be done, or how much impurity may be left in the fleece, it is known in the market as washed wool." (W. H. Brewer, ibid., p. 87.)

Raw wool, of ordinary grades as it comes to the manufacturer, contains a third or more by weight of organic matter that it is necessary to remove. This removal is accomplished by scouring in alkaline solutions, chiefly soda ash, but also, in some of the mills at least, in urine, the latter being used, I have been told, to give a softer finish to the goods than can be obtained from the ordinary alkalies; that urine is not used more extensively in many of the Connecticut mills is due to the

* For more complete discussion of the constituents of paper mill wastes, see A Study of Paper Mill Wastes, in Chapter XVI.

difficulty of procuring it. The amounts of alkalies returned by four different mills for each thousand pounds of raw material treated, are as follows :

Sal Soda	48	130	22	150
Soda Ash	75	32	50	
	128	162	72	150

Of this amount of wool, treated by these and other detergents, probably at least three hundred pounds are removed.

In English mills, where urine is used extensively, in this first washing about five hundred pounds are used to the thousand weight, with about fifty pounds of alkalies. As my reports show, a much larger amount of the alkalies is used in the Connecticut mills, and but little urine, at least I was so told by several manufacturers. All this refuse goes into the stream. After rinsing the next process, in the manufacture of fine black cloths, is that of "woading," in which the wool is steeped for a short time in a solution of indigo. This solution is used constantly with fresh additions and the only part that finds its way into the stream is the little that is removed from the wool in rinsing. From two of my reports I find not more than six or seven pounds of indigo given daily for each thousand pounds of raw material.

The next step is dyeing, in which the chief substance used is logwood. Four of the mills, from which I have reports of the dyestuffs and the raw material, give from three to five hundred pounds of the logwood for each thousand pounds of raw wool. With the logwood and other organic dyestuffs (fustic, camwood, madder, etc.) are used in different methods of dyeing, various mordants, the chief of which is copperas, the next argols (crude cream tartar), then bichromate of potash, alum, blue vitriol and tin crystals or muriate of tin. The wool after having been boiled in the dyeing vat for an hour or more is well washed in running water, and the contents of the vat turned into the stream. As a half or two-thirds as much dye material is used as the wool weighs it is very certain that only a small proportion is absorbed in the cloth. It is this waste material that discolors the streams so much, and which causes the chief complaints by the inhabitants along the streams. The amount of spent dye-liquor turned into the streams has been estimated at 6,000 U. S. gallons for each thousand pounds of raw material treated, by the British Commission.

After the wool has been dyed and dried it is prepared for carding by the reception of oil. One report gives about twelve gallons of lard oil for each thousand pounds of raw material; another about ten gallons. In English manufactories about one-tenth part by weight of sweet oil is given for the washed wool, which does not seem to be far from the quantity above given of lard oil. After having been spun, the thread may receive a small quantity of thin glue before weaving. This oil and glue is washed out and removed by the aid of soda and urine after weaving; the washings of course finding their way into the water. The remaining treatment is by soap in fulling the cloth, each piece requiring from twelve to fifteen pounds. This soap, where I have seen it, is of a pure white color, and in some of the reports it is given as "palm oil" soap.

The chief and worst polluting material in these processes is the natural grease and allied matter washed from the wool, and, next to this, the lard oil and organic dye-stuffs. The soap is much less important, and the inorganic chemicals harmless, or positively beneficial in counteracting the organic matter It is to be understood, however, that not all the woollen mills manufacture from the raw material, or do it only to a small extent.

There are several manufactories either in whole or in part, of old wool, and in which a different process is used, and one that causes less pollution—in a sanitary sense—than do the manufactures from the raw wool. The material here is of two kinds, that composed wholly of wool, and that, the larger part, containing more or less cotton. In the former the process is not very different from that employed in ordinary wool, the rags having been first reduced to wool by especial machines for the purpose. The washings and scourings of this material remove the grease and

dirt of the rags, an important polluting substance, it is true, but much less in quantity than the grease from the natural wool. In the larger proportion of rags, however, the cotton must be removed, requiring very different treatment, and a treatment that must largely, if not entirely, disinfect them. They are treated with a dilute solution of sulphuric acid in order to convert the cotton fibre into cellulose, as in the treatment of old rubber material. The acid is dried in and then washed out; the material is then dyed and manufactured by the ordinary processes. In the scouring processes alkalies and soaps are used, as in ordinary wool, but there is proportionately more of the alkali and less of both in proportion to the amount of raw material treated.

COTTON MANUFACTURE.

The cotton manufactures on the streams investigated are either of ginghams, or mixed wool and cotton goods, and are not extensive as compared with the other classes of manufactures. The wastes are both organic and mineral, but chiefly the former. The chemicals reported in the manufacture of ginghams are as follows :

Sulphuric acid.	Pearl ash.
Nitric acid.	Stannate of soda.
Muriatic acid.	Brown sugar of lead.
Chloride of lime.	Indigo.
Sal soda.	Cutch.
Soda ash.	Sumac.
Bichromate of potash.	Logwood,
Alum.	Soap.
Copperas.	Aniline colors.
Blue vitriol.	Oils.
Lime.	

Of the mineral matters, the most important are lime, chloride of lime, and bichromate of potash. Of the organic dye-stuffs, logwood.

It is very evident that all, or very nearly all, of the mineral matters are waste ; with the exception of a small part of the mineral mordants, none of them are contained in the finished goods, and consequently they are lost in the process of manufacture. This is especially the case with the lime and alkalies, the latter of which are used in small quantities. The acids are used in bleaching to counteract the effects of the lime. The soap is used—not to clean, but to soften the yarn in the process of dyeing, and in bleaching to neutralize the acids.

Bichromate of potash, alum, copperas, blue vitriol, stannate of soda, and the acetate of lead are mordants, used to impregnate the cotton, and with which the coloring matter unites to form a chemical compound insoluble in water. After the dyeing, the excess is removed by washing, and, to render the quantity absorbed absolutely insoluble, in calico print works it is customary to treat the goods to a hot emulsion of cow's dung. To what extent, if any, the dunging-process is used in gingham-dyeing, I do not know; but the process can be substituted by other processes not involving the use of dung.

The waste of the actual dye-stuffs in cotton-dyeing is large, owing to the fact that the coloring principle forms, usually, only a small proportion of the crude stuffs, as used. A firm, employing three hundred operatives, reported the consumption of logwood, and the other dye-stuffs, at over ten thousand pounds per annum ; but this amount is very small compared with what is actually used in print works.

A much smaller proportion of organic matter is removed from the fibre in the treatment it is subjected to prior to weaving than is the case in woollen mills. It is estimated that about five per cent. in weight of the raw cotton is removed in bleaching, or in the prior treatment with soda. This waste is chiefly coloring matter and fatty acids, and is not putrescible, or, is so only to a very slight extent, due to a very small quantity of albuminous matter. The removed

matter will not cause a stench, if allowed to remain in a concentrated form, exposed to the atmosphere. Even the larger mills on the Hockanum cannot contribute more than one hundred pounds daily of this waste to the stream pollution.

Of the oils used in spinning, chiefly olive oil, at least one half is waste.

Here, as elsewhere, the aniline colors, when used, give but comparatively little waste.

To recapitulate : the acids, lime salts, and alkalies are virtually wholly turned into the stream; at least one-half of the mordants are lost, and not far from the same proportion of the dye-stuffs used in the mills reported ; all of the soap, one-half of the oil, and perhaps one-tenth of the anilines is wasted ; and five or six per cent. of the raw material. When dung is not used, the putrescible waste is very small. Where starch is used, practically none is waste.

SILK MANUFACTURES.

There are but three silk mills in the region examined, but they are important, both by reason of their size, and their effects upon the streams.

Raw silk is covered with a so-called "gum," which it is necessary to remove that the silk may not have the elasticity and stiffness that it otherwise would. For the following in relation to this "silk-gum" I am indebted to Professor Johnson :

"Silk-gum (sericine) has the following composition in parts per hundred :

Carbon	44.32
Hydrogen	6.18
Nitrogen	18.30
Oxygen	31.20
	100.00

"Its empirical formula is $C_{15}H_{25}N_5O_8$. It is similar to gelatine in chemical composition and characters, but has 6 per cent. less carbon, 1 per cent. less hydrogen and nearly ½ per cent. more oxygen. It is destitute of sulphur, of which gelatine contains 0.56 per cent."

"It yields by action of hot dilute acids and oxidizing agents, products similar to, and in a great part identical with, those yielded by gelatine, albumen, etc."

This sericine constitutes from twenty to twenty-five per cent. of the raw silk, and is chiefly soluble in water. It may be removed by maceration, which produces a most intense and disagreeable stench, or it may, as is usually the case, be removed by scouring in a weak solution of soap. The soaps used are of the best olive-oil kinds, and a very large quantity is required in large mills. The soap is dissolved in hot water, and, if the goods are not intended to be dyed, the silk is boiled in the solution for an hour or more ; if the silk is required white, it is first treated for several hours in a warm solution. After scouring, the silk is thoroughly washed, and all refuse, both scourings and washings, are turned into the stream. Whether raw silk is treated as such, or in the cocoons before reeling, the processes so far as refuse is concerned, can not be very different.

The further processes are those of dyeing, which, so far as the stream is concerned, are wholly of secondary importance. But little oils are used, and the organic refuse is almost wholly the extractive matter of various dyewoods. Proportionately there is less waste of dye-stuffs from the silk mills than from those of other kinds of fabrics. Aniline colors here form a very important part, and of them, owing to their expensiveness, there is less waste.

HAT MANUFACTURE.

The waste products in the process of hat manufacture from fur are considerable in quantity, and of a kind that discolor very much the waters of streams that receive them. The character of these wastes, however, is of a kind that ac-

tually pollute the streams much less than would be supposed from the visible effects produced, and far less than is caused by the wastes from woolen mills, consisting as it does in Connecticut, chiefly of dye-stuffs. Almost the whole of the hatting industry in this State, as is well known, is confined to Norwalk, Bethel, and Danbury, which supply a large part of the hats worn in the United States, the only other manufactories of importance being those of New Jersey. In Danbury and Bethel, the two places under consideration in this report, the furs are, mostly, purchased ready prepared, and the most of the most deleterious process, so far as the stream is concerned, thus avoided. There are, however, two fur-cutting mills in Danbury, which furnish a large portion of the carreted fur for that city.

When the fur is cut, the first process that the skins undergo is that of washing. The skins, chiefly those of the coney, and nutria, are imported in bales from Australia, South America, and elsewhere, and contain a considerable quantity of foreign matter, in the shape of sand, dirt, etc. These skins are first placed in large tubs of hot water and allowed to soak, after which they are washed, rubbed, and rinsed, about twenty-five pounds of whale-oil soap being used to each thousand pounds of skins. The water thus used is run into the stream, and must contain a considerable quantity of offensive organic matter, the waste having a very whitish color. The actual quantity of polluting material cannot, however, be very great in Danbury, for altogether only about three thousand pounds are washed daily, and with seventy-five pounds of soap, not a very large amount of greasy matters can be washed out. I can give no estimate of what this quantity is, for such could only be obtained by carefully weighing the skins before and after washing, and then, too, the inorganic matter removed could hardly be determined without special examinations therefor. In the treatment of raw wool, a fourth to a third of the actual weight is washed away by the alkalies, but, in the furs, there can be but little fatty matter removed from the hair itself.

The other processes of shearing and carreting do not require the waste of water, I was told. Carreting is that process which gives the shrinking or felting property to the fur required to bring it into the desired compact shape, and consists of a treatment with the nitrate of mercury. The process has long been known to have a very injurious result upon the health of the workmen engaged in the various hatting processes ; not so great, perhaps, in the actual carreting as in the forming and pressing of the hats. Since the general use of stiff hats has come into vogue, there has been a decrease in the extent of mercurial poisoning, especially in Connecticut, where comparatively few soft hats are made. The manufacture of soft hats requires in finishing a much greater use of the pressing iron on the damp felt, and a corresponding greater inhalation of the mercurialized vapor. Perhaps, also, the shellac now used prevents the vaporization of the mercury. Still, there is not a little mercurial poisoning among the operatives, especially in the hat-forming shops.

The dyers' waste liquors are constantly escaping from the factories, partly as rinsings from the hats, but chiefly from the dye-tubs themselves after they are no longer of sufficient strength to serve their purpose. There is a difference among the different manufactnrers as to the frequency with which the dye-tubs are emptied, but there seems to be little difference in the amount of dye-stuffs used for a given number of hats.

Logwood forms by far the chief material used, inasmuch as black hats are those chiefly worn ; the other dye-stuffs are used in the production of different effects, or the lighter colors, but their effect on the stream is essentially the same. The following is a recipe given me by one of the manufacturers, and differs only in unessential details from those used by the hatters in general :

Bichromate potash	$1\frac{1}{4}$ lb.
Argols	$1\frac{1}{4}$ lb.
Madder	2 lbs.
Cudbear	$\frac{3}{4}$ lb.
Blue vitriol	4 oz.
Logwood (chips)	60 lbs.
Fustic	3 lbs.
Madder	1 lb.

The above is the quantity required for the dyeing of twelve dozen stiff hats. Soft hats require rather a larger quantity, and the extract of logwood is used in place of the chips, about ten pounds being required for each gross of hats. The logwood chips, after the coloring matter is extracted, are either burnt or thrown upon the ground. As ten pounds of the extract takes the place of the chips in dyeing the soft hats, it is evident that five-sixths of the logwood chips is non-coloring matter. Alum, in the proportion of three ounces to the dozen hats, is used by some hat-makers.

The manufacture of wool hats, which is carried on only to a small extent, produces proportionally a much greater degree of contamination. The treatment of the material is here not much different from that in woolen mills, except in the use of oils. The raw wool is scoured with alkalies to remove the natural greasy matters, and afterward treated much like the ordinary fur, the chief refuse being the logwood and similar dye-stuffs.

The hat-forming shops, of which there are two or three in Waterbury and Bethel, receive the carreted fur from the different manufacturers and beat it loosely into conical bags by machinery. The fur is first placed in a blowing or separating machine, where it is finely and evenly mixed. It is then removed, weighed out into proper amounts, and run through a machine that beats it loosely into large conical bags. Next, the bags are dipped in water and rolled several together in a cloth to give sufficient consistency to handle, and are then sent to the hat-shops. The only refuse, in forming, it is thus seen, is that carried off in the water in which the bags are dipped, and must be small in quantity.

The next process these conical bags undergo is that called sizing, and consists of repeated dippings in hot water and rolling with the hands, which produces the shrinkage or felting of the material necessary to bring them to the required size. The water in which they are dipped, carrying with it a small amount of refuse, is turned into the stream. After drying and shaving to remove the projecting fur they go into the dyer's hands, where they are subjected to the ordinary vegetable dyes, such as logwood, camwood, madder, fustic, hypernick, etc., the refuse of which, chiefly logwood, forms almost the whole of the contaminating waste, the treatment with shellac, drying, pressing, and curling producing little or none. The short particles of fur shorn from the hats, with other dry waste, is used wherever practicable, or when not, is usually destroyed, used for fertilizing material, or otherwise disposed of. At the most, but little of it gets into the streams.

RUBBER MANUFACTURE.

In the ordinary manufacture of rubber there can be but little waste of a deleterious nature. The only use of water is in the washing of the raw gum, to remove the adhering dirt; and to cool the rolls when they get too hot. The bisulphide of carbon is about the only chemical used, and this for a solvent to cement the different pieces of rubber; there can but little of it get into the stream.

In the manufacture of reclaimed rubber goods, there is a source of considerable refuse in the treatment the material undergoes in the removal of the vegetable fibers contained in it. As in the treatment of cotton and wool shoddy material, the old rubber is soaked in a dilute solution (13° Beaumé) of sulphuric acid; this attacks the vegetable fiber, converting in into the soluble cellulose, which, with the spent solution is washed out and turned into the stream together with a quantity of alkali (about ten per cent. of the acid), used in neutralizing the acid.

The balance of this Report is chiefly occupied with detailed statements of the specific sources of pollution in the state, the amounts of the various polluting materials and chemical and bacteriological analyses of the waters of several of the streams being given.

In the Eleventh Annual Report of the Connecticut State Board the

Rivers Pollution Report is continued by Professor Williston with further detailed statements of sources of pollution and chemical and bacteriological analyses of a number of water supplies of the State. Reports of progress are given in the Twelfth and Thirteenth Annual Reports, and the complete results appear in the Fourteenth Annual Report, covering the year from December 1, 1890, to November 30, 1891.

Of the results in the Fourteenth Annual Report brief reference will be made to the analyses of the Connecticut river water, samples of which were analyzed from three points, namely, Warehouse Point, Rocky Hill, and Goodspeed's.

Warehouse Point is about 13 or 14 miles below Springfield, and not far from the north line of the State. The samples taken here show the composition of the water as it enters the State and after pollution by the sewage of Northampton, Holyoke, Chicopee, and Springfield in Massachusetts.

Rocky Hill, the second point from which samples were examined, is about 20 miles below Warehouse Point, and 9 miles below Hartford. Between this place and Warehouse Point the river receives its chief tributaries in Connecticut, which are the Farmington, but slightly polluted; the Park river, which is grossly polluted by the sewage of New Britain and Hartford; and the Hockanum, into which is discharged the sewage of Rockville and Manchester.

Goodspeed's is about 22 miles below Rocky Hill. The chief pollution between this station and Rocky Hill is at Middletown, about 15 miles above Goodspeed's.

The samples were all taken on the same day at each station and always from the same point, well out in the current and one foot below the surface.

The series extend from August, 1890, to June, 1891, the samples for analysis being taken about the 25th of each month. The following table shows the average discharge of the river at Hartford for the ten days preceding the dates on which the samples were taken.

	Average discharge in cu. ft. per sec.		Average discharge in cu. ft. per sec.
June, 1890	10,320	Jan., 1891	64,370
July "	7,740	Feb. "	39,120
Aug. "	8,310	March "	54,200
Sept. "	41,280	April "	89,530
Oct. "	41,820	May "	26,460
Nov. "	26,930	June "	9,800
Dec. "	16,450	July "	8,025
		Aug. "	7,550
		Sept. "	7,550
		Oct. "	7,360

The means of the monthly analyses are given in the Table No. 4 c.

TABLE NO. 4 C.—MEAN RESULTS OF ANALYSES OF CONNECTICUT RIVER WATER, MADE IN 1890 AND 1891.

(Parts per 100,000. Water filtered through paper.)

Locality.	Number of analyses in series.	Color.	Suspended matter.		Residue on evaporation.			Chlorine.	Nitrogen.				Hardness as $CaCO_3$.	Oxygen consumed from pemanganate. ½ h.. at 100° C. (212° F.).
			Fixed.	Volatile.	Total at 100° C. (212° F.)	Loss on ignition.	Fixed.		Of free ammonia.	Of albuminoid ammonia.	Of nitrites.	Of nitrates.		
Warehouse Point	11	0.3	2.09	.27	4.42	.86	3.56	.123	.0034	.0126	.00018	.012	2.3	.519
Rocky Hill	11	0.3	0.178	.22	4 46	.87	3.59	.128	.0033	.0135	.00019	.011	2.5	.504
Goodspeed's	11	0.3	0.138	.29	4.50	.88	3.62	.136	.0036	.0138	.00015	.013	2.5	.492

The Connecticut river is not used as the source of a public water supply at any point in the State except at Hartford, where it is intended to be used as an emergency supply only. The conclusion of the report is that while the analyses show that the sewage entering the stream has scarcely a perceptible effect on the chemical composition of the water, nevertheless it is unsafe for drinking at any point in Connecticut.

NEW JERSEY.

In New Jersey the question of rivers pollution is in an exceedingly unsatisfactory state. A high court of the State has recently indorsed the opinion that the sewage from 15,000 people can enter a stream having a minimum daily flow of 125,000,000 gallons, already largely polluted, and flow only four miles on a level reach before entering the public water supply of 400,000 people without demonstrated danger.* The only law in this State dealing with the pollution of streams is one passed in 1876,† which is stated as entirely inadequate to deal effectively with the evils of stream pollution. Its text is open to various constructions and its letter and spirit are constantly violated.‡ In a report presented to the New Jersey Sanitary Association in 1890

* Bassett, Inland Sewage Disposal, Trans. Am. Soc. C. E., vol. xxv., p. 129.

† *An Act to Prevent the Willful Pollution of Water of any of the Creeks, Ponds, or Brooks of the State.*

That if any person or persons shall throw, cause or permit to be thrown into the waters of any creek, pond, or brooks of this State the waters of which are used to supply any aqueduct or reservoir for distribution or public use any carcass of any dead animal or any offal or offensive matter whatsoever, calculated to render such waters impure or to create noxious or offensive smells, or shall connect any water closet with any sewer or other means whereby the contents thereof may be conveyed to and into any such creek, pond, or brook, such person or persons shall be deemed guilty of a misdemeanor and on conviction thereof shall be punished by a fine not exceeding $1,000, or by imprisonment not exceeding two years, or both. (Approved, April 21, 1876.)

‡ Report of Committee of New Jersey Sanitary Association, presented Dec. 13, 1889. In Eng. News, vol. xxv., p. 111 (Jan. 31, 1891).

the state of the question in New Jersey is fully discussed, and the recommendation made that an act be passed empowering the State Board of Health to act as arbitrator in all matters affecting the pollution of streams, water courses, and lakes.

In this State studies of stream pollution thus far have been chiefly by the chemical methods and in reference to the pollution of the Passaic river, which until 1892 was the source of the water supply of the large cities of Newark and Jersey City, and from which stream the water supply of Jersey City is still drawn, although efforts are being made to secure a new supply. Some of them are published in the earlier reports of the New Jersey State Board of Health. Sources of pollution from manufacturing wastes are also discussed in the Report of the Newark Aqueduct Board on Additional Water Supply, published in 1879.

The Pollution of the Passaic River.

An extended discussion of the pollution of the Passaic from the chemical point of view is published by Henry Wurtz, Ph. D., formerly State Chemist of New Jersey, in The Engineering and Mining Journal for March 22, and April 12, 19, and 26, 1890. The matter there given is the substance of a report on the waters of the Passaic river and its tributaries, presented to the Board of Aldermen of Paterson in 1882, and covers the examination of a series of samples collected between September 7, 1881, and January 7, 1882. Previously Mr. Wurtz had made two reports in reference to the Passaic waters, namely, in March and October, 1873; the first, referring to the condition of the water during the fall and winter 1872–73; the second, to the summer of 1873. Both of these reports appear in Vol. IV. of the American Chemist, but the present report is of greater interest by reason of giving Mr. Wurtz's recent views on the pollution and self-purification of this stream, which serves as the present source of water supply for Jersey City.

The report of 1882 covers a series of chemical analyses of the water of the Passaic river and its tributaries, including also a few comparative analyses of the water of the Croton river. Its chief object is apparently to substantiate the view advanced in the report of 1872 that "the oxidizing power of this alkaline river water is so great that but slight traces of the sewer matter can be detected after flowing but four miles through the channel." On this point Mr. Wurtz considers the showing specially strong by reason of the prevalence of a severe drouth not only previous to the beginning but during nearly the whole time covered by the investigation, there being no rainfall which contributed anything appreciable to the flow of the river or its tribu-

taries from early in July, 1881, to December 29. Moreover no ice formed on the Passaic until about January 3, 1882; and Mr. Wurtz deems it probable that never before was such an opportunity offered, "to examine a question of river pollution, during so long a time, without disturbance of the uniformity and normality of the composition of the stream through natural agencies." This fact confers upon this work a value and importance in some respects wholly unique. As illustrative of this proposition a series of analyses of samples from different parts of the river are given. The first of these, following the general table of all the analyses made, is of water from above the high falls in the city of Paterson.

The next tabulation covers samples taken between the outlets of several of the Paterson sewers at the Straight street bridge, and the Broadway bridge below, a distance of some $4\frac{1}{2}$ miles along the stream. For the first two miles the flow is sluggish and according to Mr. Wurtz "a narrow sewage-laden strip of the current closely hugs the right hand bank in a very curious way." At the other side of the river the bottom is densely overgrown with water weeds. A flow of this character for two miles brings us to the Race track bridge, below which the current is rapid and usually rippling, diffusing the sewage all across the bottom. In this portion of the channel the weed bed extends the whole width of the channel and the following extract from the report will indicate the chief reason for most of the changes which take place, together with Mr. Wurtz's views of the sufficiency of the purification attained:

The weed-bed also here spreads all across, and the water is thus filtered through this half-mile of dense and matted vegetation, feeding both the weeds and vast colonies of crustaceans and mollusks which swarm throughout them. Much below these rapids, and even all around the Dundee lake below, shallow margins still show the weeds under water. Columns 13 and 14 of Table IV.* bring out quite satisfactorily the purifying action here of aëration in this alkaline river water, together with that of the plant and animal life. Thus, compare the total N in the three sewage-stream samples, 2, 34, and 26 = .0579 in the mean; with the three from the Broadway bridge, 3, 45, and 47 = .0309 in the mean, showing a large loss of putrescible nitrogenous matters. This diminution is not due to mere dilution of the sewage-stream throughout the whole river, as is shown by comparison with Table III. There, three N-figures above the falls, before receiving the sewage, give a mean of .0322, even a little more than at the Broadway bridge. We are forced to admit, therefore, that this flow of $4\frac{1}{2}$ miles from the mouths of the sewers has actually destroyed the total animal and animalized matter introduced by the drainage of the 50,000 inhabitants of Paterson. Moreover, the greater part of this effect appears due to the last $2\frac{1}{2}$ miles of such current.

Further, the same surprising phenomenon is shown under winter conditions of the stream; as seen by comparison of No. 46, Table III., and No. 47, both of January 7th, 1882, with the stream frozen and somewhat swollen—No. 46, above the falls, yielding .0389 of total N and 47, at Broadway bridge .0363; a proportionate reduction even twice as large as before.

* Roman numerals designate original table numbers, as given in the table headings in parentheses.

TABLE No. 5 (TABLE III. OF MR. WURTZ'S REPORT).—ANALYSES OF WATER OF THE PASSAIC RIVER ABOVE THE GREAT FALLS AT PATERSON.

(Grains per U. S. gallon.)

2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
Original numbers.	Dates.	Total solids.	Combustible and volatile.	Ash.	Chlorine.	Common salt.	Sulphuric oxide, SO_3.	Ammonia (as such).	Ammonia (albuminoid).	Ammonia (from nitrogen acids).	Ammonia. Total.	Nitrogen. Total.
1 .	Sept. 7, 1881	4.934	0.711	4.223	....	0.286	0.521	.00248	.0053	.0187	.0264	.0217
18..	Sept. 29, 1881	4.875	0.991	3.884	....	......	0.690	.00851	.0181	......	......	......
25..	Oct. 31, 1881	4.969	1.400	3.569	...	......	0.779	......	......	......	......	......
33..	Nov. 14, 1881	5.016	1.266	3.750	....	0.124	1.020	.00554	.0088	.0204	.0347	.0286
44..	Dec. 31, 1881	......	......	......	....	......	......	......	......	......	......	......
46..	Jan. 7, 1882, river ice-bound	4.794	1.458	3.336	....	0.172	1.003	.00642	.0160	.0239	.0472	.0389
	Means	4.918	1.166	3.752	...	.194	0.802	00560	.0125	.0210	.0391	.0322

TABLE No. 6 (TABLE IV. OF MR. WURTZ'S REPORT).—ANALYSES OF WATER OF THE PASSAIC RIVER BETWEEN THE GREAT FALLS AND DUNDEE LAKE.

(Grains per U. S. gallon.)

1.	2.	3.	4.	5.	6	7.	8.	9.	10.	11.	12.	13.	14.
Original numbers.	Localities.	Dates.	Total solids.	Combustible and volatile.	Ash.		Common salt.	Sulphuric oxide. SO_3.	Ammonia (as such).	Ammonia (albuminoid.)	Ammonia (from nitrogen acids).	Ammonia. Total.	Nitrogen. Total.
2..	Bleecker street, from sewage stream	Sept. 7, 1881	6.135	1.020	5.115	..	.495	0.340	.0356	.0166	.0247	.0769	.0633
34 .	West end of race-track bridge, in sewage stream	Nov. 14, "	5.873	1.557	4.316	..	.381	1.048	.0102	.0350	.0321	.0773	.0637
36 .	West end of Fifth avenue bridge, in sewage stream	" "	6.059	1.755	4.304	.	.276	1.197	.0175	.0233	.0266	.0674	.0555
35 .	East end of race-track bridge.	" "	.....	....	.....	..	....	.....	.0169	.....	.0088	.....	.....
13..	Fifth avenue bridge	Sept. 21, "	5.132	1.166	3.966	..	....	1.079	.....	.....	.....	.....	.....
3..	Broadway bridge	Sept. 7, "	5.931	1.312	4.619	..	....	0.382	.0019	.0088	.0195	.0303	.0250
47..	Broadway bridge, river ice-bound	Jan. 7, 1882	5.237	1.749	3.488	.	.285	0.977	.0041	.0181	.0219	.0441	.0363
....	Means of the sewage stream, Nos. 2, 34, and 36	....	6.022	1.444	4.578	..	.384	0.862	.0211	.0250	.0278	.0739	.0579
....	Means of Broadway bridge, Nos. 3 and 47	....	5.584	1.531	4.054	..	.285	0.680	.0030	.0135	.0207	.0372	.0307
....	Means of Table III., above Falls (repeated for comparison)	....	4.918	1.166	3.750	..	.194	0.802	.0056	.0125	.0210	.0391	.0322
....	Net increase within Paterson City limits	....	0.666	0.365	0.302	..	.091	decrease	decrease	.0010	decrease	.0011	.0010
45..	Flooded river at Broadway bridge	Dec. 31, 1881	3.855	1.166	2 689	..	.086	0.936	.0044	.0169	.0169	.0282	.0315
....	Means of all Broadway bridge, Nos. 3, 47, and 45	....	5.008	1.409	3.600	..	.285	0.765	.0035	.0146	.0194	.0375	.0309

The report farther considers the effect of the Dundee lake in assisting the process of self-purification; for this purpose examinations were made at different times of the water of its outlet, the Dundee canal, with the expectation of gaining thereby information relative to the

average composition better than by studies of samples taken from the lake itself. This canal is in effect a mill race about 1¾ miles in extent, leading from the lake to the mills at Passaic city, and discharging into the tidal stream below. The results are included in Table No. 7 following, where Mr. Wurtz has placed them in comparison with the means of the analyses of samples taken from points above as exhibited in Tables No. 5 and 6.

TABLE NO. 7 (TABLE V. OF MR. WURTZ'S REPORT).—ANALYSES OF WATER OF THE DUNDEE CANAL AT AND NEAR THE CITY OF PASSAIC.

(Grains per U. S. gallon.)

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
Original numbers.	Localities.	Dates.	Total solids.	Combustible and volatile.	Ash.		Common salt.	Sulphuric oxide. SO_3.	Ammonia (as such).	Ammonia (albuminoid).	Ammonia (from nitrogen acids).	Ammonia. Total.	Nitrogen. Total.
		1881.											
9..	Canal at Passaic.....	Sept. 9	6.275	1.312	4.963	......	0.429	0.590	.0007	.0070	.0280	.0357	.0294
19..	Exit from lake into canal; at west end of dam	" 29	5.587	1.050	4.537	......	......	0.691	.0047	.0093	.0146	.0280	.0235
26 .	Canal at Passaic.....	Oct. 31	5.552	1.050	4.502	.....	0.505	1.156	.0021	......	......	.....	......
41..	Canal at Passaic, river in flood......	Dec. 30	6.777	3.674	3.103	......	0.371	0.954	.0085	.0105	.0090	.0271	.0231
....	Means*..............	....	5.805	1.104	4.276 or 4.667	......	0.435	0.848	.0040	.0089	.0172	.0304	.0250
...	Means of Broadway bridge; Table IV.	....	5.008	1.409	3.600	......	0.285	0.854	.0035	.0146	.0194	.0375	.0309
	Increase in traversing Dundee lake..	....	0.797	...	0.676	......	0.150	......	.0005	......	......	......	......
	Decrease in traversing Dundee lake..	....	......	0.305	......	......	......	0.006	.....	.0057	.0022	.0071	.0059
....	Means above falls; Table III.	....	4.918	1.166	3.752	......	0.194	0.802	.0056	.0125	.0210	.0391	.0322
	Increase from falls to Passaic city	....	0.887	.. ..	0.915	......	0.241	0.046	...	......	......	......	......
	Decrease from falls to Passaic city....	....	......	0.062	......	......	......	......	.0016	.0036	.0038	.0087	.0072

* Regarding these mean figures, one point needs explanation. As stated, the flood sample 41 was turbid when analyzed, and the total solid and combustible matter were both therefore overestimated. In the means of columns 4 and 5, therefore, the figures of 41 have been neglected. Not so with the ash, however (column 6). Here two mean figures have been computed, the first with, and the second without, No. 41. It will be observed that the mean of the waters above the falls does not include a flood sample, this having been duly collected, but broken and lost in transit (See Table I., No. 44). It was judged proper, therefore, to compute the figure .915, representing the increase of mineral matter from the falls to the lake-outlet, from the second mean 4.667, without the flood water. The figure .676, however, the increase of mineral matter in the lake, does include the flood water, as it is the difference between two means, both containing flood-water figures.

The balance of the report is occupied with a discussion of (1) the pollution of the tideway portion of the Passaic river below the city of Passaic by the sewage of Newark; and (2) with a brief discussion of the quality of the water of the Morris canal as representing the pure water of the upper tributaries of the Passaic. The tables illustrating these points, while interesting, are less valuable than those included in the foregoing, so far as indicating the possible extent of the self-purification of a running stream. The final tabulation giving the

chemical changes in the water of the Passaic river at six stages of its flow may be included as pertinent to the present discussion.

TABLE No. 8 (TABLE XIII. OF MR. WURTZ'S REPORT).—SHOWING THE CHEMICAL CHANGES IN THE WATER OF THE PASSAIC RIVER AT SIX STAGES OF ITS FLOW.

(Grains per U. S. gallons.)

1.		4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
No. of stage.	Stage of the river.	Total solids.	Total organic matter.	Mineral.		Common salt.	Sulphuric oxide, SO_3.	Ammonia (as such).	Ammonia (albuminoid).	Ammonia (from nitrogen acids).	Ammonia. Total.	Nitrogen. Total.
1...	Uncontaminated head waters, Morris canal; mean of 4, at different dates..............	3.165	1.064	2.101	......	0.190	0.511	.0023	.0062	.0083	.0167	.0135
2...	River entering Paterson, above falls; mean of 5, different dates....	4.918	1.166	3.752	......	0.194	0.802	.0056	.0125	.0210	.0391	.0322
3...	River leaving Paterson, Broadway bridge; mean of 3, different dates................	5.008	1.409	3.600	......	0.285	0.765	.0035	.0146	.0194	.0375	.0309
4...	River leaving Dundee canal; mean of 4, different dates...	5.805	1.104	4.667	......	0.435	0.848	.0040	.0089	.0172	.0304	.0250
5...	Down flow in tidal channel; mean of 5, different dates...	6.752	1.394	5.358	......	0.938	1.081	.0101	.0090	.0364	.0508	.0418
6...	Up flow, carrying Newark sewage; mean of 5, different dates	31.710	5.396	26.514	......	21.193	2.084	.0111	.0159	.0375	.0667	.0549

The conclusions are stated in the following language:

A general review shows that we have obtained quite complete and satisfactory data regarding the chemical composition of the Passaic at six important stages of its flow, during the four months of September to December, inclusive, 1881. In the course of this report there have been presented, moreover, rational and consistent theories of the causes of the principal changes of composition throughout these six stages. In Table XIII. they are presented in succession.

First Stage.—This is represented by the Morris canal, chiefly and directly fed from the Highland hillstreams of your State, unexcelled in purity. Lake Hopatcong, the Summit canal reservoir, it should, however, be remarked, does not naturally belong to the Passaic watershed, but to that of the Delaware; its tributaries, nevertheless, interlock with those of the Passaic, and rise in the same crystalline rocks.

Second Stage.—Represented by the river just above the Passaic falls. The increments shown here of dissolved matters above those in the canal cannot be attributed in any important measure to evaporation, which takes place from both channels. The salt is the same in both, the sulphates considerably larger in the river, the total organic matter but little larger, while the albuminoids are doubled, and the total nitrogen more than doubled in the river. This last increase, with that of the sulphates, is easily traceable to the much larger drainage from animals and fertilized lands received by the river before arriving at this stage.

Third Stage.—Represented by the river at the Broadway bridge, before entering the Dundee lake, after receiving the total sewage of Paterson, but subsequently furnishing nourishment to extensive masses of aquatic plants and animals, and rippling through some miles of shallow rapids, which, with the aëration and oxidation consequent upon these conditions, and upon the basic composition of this river, has effected the absolute absorption and destruction of almost the whole of the Paterson sewage matters. Of the latter, the only chemical evidences left are

the salt, which has been increased about 50 per cent., the total organic matter, which has increased only 21 per cent., and the albuminoids, which now average more than double the proportion in the first stage, the canal, though still not large enough to condemn the water for potable purposes, even at this point. Moreover, the total nitrogen has been kept down, so that it barely exceeds that above the falls. The sulphates, by fertilizing the water weeds, have actually been reduced in amount.

Fourth Stage.—Represented by the current in the Dundee lake outlet, or Dundee canal. The water has here undergone evaporation, but at the same time much further aëration and depuration by its slow passage through the expanse of the lake. Thus, we find that, while the total solids have increased by concentration, the total organic matter has been partly consumed, so that it has fallen to less than 4 per cent. more than in the first stage. The salt and sulphates have both increased, while the albuminoids have now decreased to a figure not greatly above the first stage, and the total nitrogen has also decreased nearly 20 per cent. during the lake passage, so that now both this and the albuminoids are appreciably less (the former 22, the latter 29 per cent. less) than above the Falls before entering Paterson.

Fifth Stage.—Represented by what we have concluded to be the "normal" composition of the downflowing tideway waters when free from the great influx of sewage from Newark. The increase of nearly a grain per gallon of total solids, half of which is salt, is due to several causes, one being evaporation, another local sewage influx. The increase of sulphates, over one-fifth of a grain, may be partially from the Lodi chemical works, as already shown. The total organic matter increases 26 and the total nitrogen as much as 67 per cent., although, rather unexpectedly, the albuminoids do not increase at all, but must be destroyed by the downflowing current and converted inte the innocuous forms of ammonia salts and nitrogen acids about as fast as they enter.

These latter two components, accordingly, have increased at the rate of 152 and 112 per cent. respectively.

Sixth Stage.—Represented by samples—mostly Newark hydrant waters—showing large sewage pollution. Here the salt has increased over 22 times, the sulphates are doubled, and the total organic matters increased four-fold, over the downflowing tidal current of the fifth stage. Nevertheless, very curiously again, the albuminoids have not increased proportionately, but only about 77 per cent., now being but little more than at the Broadway bridge, at the head of Dundee lake. The destructive action of Passaic water on animal and animalized matters appears, therefore, to prevail at all stages of the river's flow. The total nitrogen in this sixth stage is but 31 per cent. larger than in the fifth stage, though 70 per cent. larger than in the water above the Paterson falls, 120 per cent. larger than in the Dundee canal, and 307 per cent. larger than in the Morris canal.

The question of the pollution of the water supplies of the large cities of Newark and Jersey City has, by reason of the extensive litigations which have ensued, become somewhat celebrated, and the essential features of the case are given in Appendix V.

Investigations in Pennsylvania.

In Pennsylvania Col. Julius W. Adams presented a Report On the Pollution of Rivers as Applicable to the Future Water Supply of Philadelphia, to the Commission of Engineers appointed to consider the entire subject of the present and future water supply of Philadelphia in 1875.* This report is followed by (1) a Report of Messrs. Booth and Garrett to the Commission, on their Examination of the

* Vol. ii. of the Journal of the Select Council of the city of Philadelphia for 1875. (Appendix A.)

Waters of the Schuykill and Delaware rivers; and (2) by a tabulation of analyses made by Dr. Charles M. Cresson.

In the Eighty-second Annual Report of the Philadelphia Water Department (1884) is found the beginning of an elaborate chemical investigation of the present and future sources of water-supply for Philadelphia, by Dr. Albert R. Leeds, the preliminary work of the first year, including a chemical study largely of the pollution of that river from various sources.

In the Eighty-third Annual Report of the Department the study of various sources of prospective future supply is continued, and Dana C. Barber, C. E., assistant engineer, reports on sources of pollution in detail. One of the Schuylkill cases cited may be reproduced here.

The principal source of contamination at the falls of the Schuylkill is the refuse waste from an extensive carpet, blanket, and cloth mill, situated a short distance from the river on a natural water-course, through which the waste products of the mill flow directly into the river. In January, 1884, the proprietors furnished the following statement of the quantity of material used per day:*

45,000	pounds of	wool scoured.
500	"	tallow (used in soap for scouring).
11	"	acetic acid.
19	"	muriatic acid.
31	"	oxalic acid.
3	"	tartaric acid.
88	"	alum.
64	"	aniline dyes.
27	"	butter of antimony.
235	"	aqua ammonia.
42	"	aqua fortis.
674	"	archil liquor.
24	"	barwood.
90	"	bi-chromate of potash.
33	"	black dye.
12	"	blue stone (blue vitriol).
3	"	borax.
245	"	brimstone.
9	"	camwood.
124	"	caustic soda.
17	"	cochineal.
7	"	copperas.
16	"	cream of tartar.
27	"	crystals of tin.
8	"	cud-bear.
24	"	cutch (catechu).
247	"	extract of bark (quercitron).
80	"	extract of fustic.
19	"	extract of indigo (acid).
165	"	extract of indigo (neutral).
22	pounds of	extract of logwood.
11	"	extract of logwood (liquid).
192	"	extract of sumac.
4	"	flavine.
7	"	fuller's earth.
47	"	chipped fustic.
2	"	gambier.
715	"	Glauber's salts.
60	"	gum substitute.
69	"	hypernic.
32	"	indigo.
3	gallons of	iron liquor.
1	pound of	litharge.
2,351	pounds of	chipped logwood.
26	"	madder.
3	"	muriate of copper.
3	"	muriate of iron.
3	"	muriate of tin (double).
16	"	muriate of tin (single).
3	"	nutgalls.
505	"	oil of vitriol.
82	"	Paris white.
36	"	pipe clay,
3	gallons of	red liquor.
2	pounds of	red sanders wood.
344	"	sal soda.
349	"	soda ash.
66	"	sumac.
4	"	turmeric.
10	"	yellow prussiate of potash.

* Eighty-third An. Rept. Phil. Water Dept. (1885), pp. 308–309.

Mr. Barber was unable to state whether or not the list included all the pollution from this particular mill, as he was denied access. The list may therefore be taken as representing the pollution which the proprietors were willing to admit. Chemical analyses showing the effect of this pollution on the stream are given in the report of Dr. Leeds.

Mr. Barber's report is also included in a Report on the Pollution of Rivers, by the Committee on Water Supply, Drainage, Sewerage, etc., of the State Board of Health of Pennsylvania, in the First Annual Report of that Board (1886).

In the Eighty-fourth Annual Report of the Philadelphia Water Department Professor Leeds concludes his report on the chemical examination of the water supply, which, with an additional short report by Mr. Barber and tables showing the extent and density of the population of the collecting areas examined, concludes the Philadelphia investigation so far as questions of stream pollution are concerned.

Minnesota.

In Minnesota, the State Board of Health has for several years made more or less systematic chemical analyses of waters throughout the state. A number of such of the water of the Mississippi river are given in the Eighth Annual Report of that Board. A few analyses of the Mississippi river water are given in the Ninth and Tenth Reports.

In 1883, Professor James A. Dodge made a few chemical analyses of the Mississippi river water at points in the vicinity of Minneapolis, St. Paul, Hastings, and Winona. The results may be found in the Bulletin of the Minnesota Academy of Science, Vol. III., No. 1.

The Illinois Studies.

In Illinois, the water supply of the city of Chicago, drawn from the lake front, is badly polluted by the sewage of the city which finds its way into Lake Michigan, largely by way of the Chicago river, into which nearly all the sewers of the city discharge.*

The pollution of the Chicago river has, however, increased with the growth of the city from year to year, and finally means were taken to force, by pumping, a portion of the polluted water of the South branch of the Chicago river through the existing Illinois and Michigan canal, thereby obtaining to some extent the relief proposed by Mr.

* See also Chapter IX., on Discharge into Tidal or other Large Bodies of Water, where the Chicago problem is further touched upon.

Chesbrough in 1855. The present plant for this purpose, erected in 1882–83, has a nominal capacity of 60,000 cubic feet of water per minute,* which is taken from the Chicago river, near where it receives, in addition to the sewage of about 400,000 people, the drainage of the Union Stock Yards at South Chicago, amounting to about 7,000,000 gallons per day of concentrated sewage.†

The work of the Chicago Drainage and Water Supply Commission of 1887 revived the project of a large, navigable canal to the Des Plaines river, and led to a study in 1888–89, by the State Board of Health, of the question of probable pollution of the Illinois river by the discharge through such a canal of the sewage of the city of Chicago diluted with 600,000 cubic feet of lake water per minute.

Before discussing briefly the results obtained in the study of the water supplies of Illinois and the pollution of its streams in 1888–89, we may refer to the fact that the State Board of Health had previously made a few similar studies, the results of which can be found in their several reports, though chiefly in the Ninth Report, for the year 1886. In regard to the results in the Ninth Annual Report, it may be observed that they are not nearly so complete as the work of 1888–89, and must be considered at the present time, in view of the extended results of the later investigation, of historical value chiefly.

Self-purification in the Illinois and Michigan Canal.

In the investigation of 1888–89, as made by Professor J. H. Long, 750 samples of water were examined between May 1 and November 15.

One of the chief objects of the investigation was to determine the rate and degree of self-purification taking place in the Illinois and Michigan canal between Bridgeport, the point where the sewage-polluted water of the South branch is pumped into the same, and its point of discharge into the Des Plaines river at Joliet, and so on down stream to the Illinois river, and finally to the Mississippi. On this question Professor Long presents among others a series of analyses at (1) Bridgeport, the head of the canal, and (2) at Lockport, 29 miles below. In this distance the canal receives nothing aside from rainfall and the slight infiltration which may possibly take place, but which is stated as nearly *nil.* During the summer of 1888, while the tests were in progress, the pumps at Bridgeport were in continual operation at the rate of 50,000 cubic feet per minute, an amount on an average for each whole day about seven times in excess of the total of sewage flowing into the river from all sources. We have, then, in this canal the ideal

* See Chapter XXII. in Part II. for description and illustrations of this plant.

† For an analysis of this stock-yard sewage see foot-note, page 32.

conditions for determining the rate of self-purification of a running stream by the purely chemical agencies. To place this in stronger light, we may note that the necessity for maintaining the canal in navigable condition precludes allowing the growth of water plants along the sides and bottom. Again, the frequent passing of heavily laden boats stirs up sediment which may have collected at or near the bot-

TABLE No. 9.—CHEMICAL CHANGES IN THE WATER OF THE ILLINOIS AND MICHIGAN CANAL WHILE FLOWING 29 MILES FROM BRIDGEPORT TO LOCKPORT.—(From analyses made by Professor J. H. Long in 1888–89.)

(Parts per 100,000.)

Place collected.	Date of collection.	Total solids.	Matter in suspension.	Nitrogen in nitrates.	Chlorine.	Hardness $CaCO_3$.	Free ammonia.	Albuminoid ammonia.	Oxygen consumed.
	1888								
Bridgeport	May 1	109.90	46.70	0.0	15.57	15.90	2.92	0.68	5.96
Lockport	May 3	53.80	4.10	0.0	7.78	27.90	1.57	0.33	2.51
Bridgeport	May 8	45.00	11.51	0.0	4.81	15.90	1.11	0.37	2.96
Lockport	May 10	60.85	24.20	0.0	2.12	18.30	0.85	0.27	2.46
Bridgeport	May 15	58.00	2.85	0.0	5.95	24.24	1.08	0.18	2.22
Lockport	May 17	69.20	10.70	0.0	3.54	25.70	1.28	0.16	1.59
Bridgeport	May 22	42.81	7.67	0.0	3.04	21.96	0.77	0.25	2.27
Lockport	May 24	46.84	5.69	0.0	3.54	26.04	0.64	0.17	1.74
Bridgeport	May 28	50.55	14.70	0.0	3.54	23.52	0.82	0.21	2.08
Lockport	May 31	69.90	8.06	0.0	12.17	26.88	1.73	0.22	2.26
Bridgeport	June 5	47.48	7.51	0.0	2.55	23.04	0.77	0.20	2.11
Lockport	June 7	42.81	6.45	0.0	2.26	22.80	1.01	0.18	1.72
Bridgeport	June 12	46.49	13.20	0.0	3.68	21.00	1.05	0.20	2.16
Lockport	June 14	38.71	5.80	0.0	2.55	21.30	1.14	0.16	1.21
Bridgeport	June 19	34.75	6.23	0.0	2.12	17.40	0.80	0.29	1.98
Lockport	June 21	32.29	4.65	0.0	2.83	19.20	0.72	0.17	1.58
Bridgeport	June 26	36.70	15.52	0.0	1.42	19.20	0.61	0.17	1.86
Lockport	June 27	33.19	4.70	0.0	3.54	20.00	1.05	0.17	1.60
Bridgeport	July 17	48.65	10.97	0.0	6.23	21.20	1.68	0.28	2.63
Lockport	July 19	34.67	3.80	0.0	5.95	21.50	1.10	0.18	1.86
Bridgeport	July 24	34.75	8.45	0.0	2.77	16.80	0.72	0.20	2.37
Lockport	July 26	34.25	4.67	0.0	3.29	16.80	1.10	0.12	1.54
Bridgeport	July 31	75.49	14.45	0.0	18.12	24.00	3.10	0.18	2.66
Lockport	Aug. 3	48.95	17.14	0.0	2.83	21.60	1.50	0.20	2.24
Bridgeport	Aug. 7	42.03	7.25	0.0	3.12	21.00	0.98	0.18	1.80
Lockport	Aug. 9	38.64	4.88	0.0	3.26	20.40	1.08	0.36	1.36
Bridgeport	Aug. 14	37.30	4.98	0.0	2.55	19.20	1.06	0.16	2.00
Lockport	Aug. 16	31.24	3.12	0.0	1.27	18.80	0.69	0.19	1.47
Bridgeport	Aug. 21	32.35	5.04	0.0	2.55	19.00	0.76	0.32	1.55
Lockport	Aug. 23	33.05	3.25	0.0	1.27	18.00	0.66	0.17	1.53
Bridgeport	Aug. 28	34.12	6.50	0.0	2.83	19.40	0.86	0.14	1.58
Lockport	Aug. 30	39.00	4.54	0.0	5.84	19.00	0.98	0.15	1.85
Bridgeport	Sept. 11	33.68	6.55	0.0	1.27	16.80	1.04	0.19	1.40
Lockport	Sept. 13	34.88	3.08	0.0	1.56	16.80	0.97	0.18	1.52
Bridgeport	Sept. 14	44.70	9.90	0.0	2.97	19.00	0.98	0.33	1.46
Lockport	Sept. 15	42.30	3.90	0.0	4.96	18.00	1.18	0.23	1.25
Bridgeport	Sept. 18	58.34	18.42	0.0	7.64	21.00	2.58	0.26	1.57
Lockport	Sept. 20	60.70	14.34	0.0	8.78	25.00	1.90	0.21	1.07
Bridgeport	Sept. 25	34.50	9.30	0.0	3.04	18 00	0.88	0.18	1.12
Lockport	Sept. 27	33.88	6.70	0.0	3.40	16.60	0.88	0.26	1.34
Bridgeport	Oct. 9	32.10	7.81	0.0	2.83	17.40	1.18	0.17	2.18
Lockport	Oct. 12	39.54	5.71	0.0	5.95	18.20	0.94	0.19	1.96
Bridgeport	Oct. 16	34.10	5.83	0.0	5.10	20.00	0.98	0.25	3.04
Lockport	Oct. 18	37.36	6.58	0.0	5.10	21.60	1.10	0.23	0.88
Bridgeport	Oct. 23	41.52	8.36	0.0	6.11	24.00	0.92	0.26	3.74
Lockport	Oct. 25	38.40	5.38	0.0	9.90	19.00	0.89	0.15	0.69
Bridgeport	Oct. 30	38.68	15.75	0.0	1.42	21.20	0.69	0.24	2.40
Lockport	Oct. 30	40.50	6.11	0.0	3.54	19.20	1.13	0.15	1.73

tom, thereby preventing the appearance of a self-purification by actual destruction of organic matter, which is in reality merely a change of position of polluting material by sedimentation. Further, in relation to sedimentation it may be stated that the current of the canal of nine-tenths of a mile an hour is sufficient to prevent it, and this fact is further said to be proven by numerous dredgings of the bottom, which show no traces of sewage subsidence. The changes which do take place may therefore be considered as due entirely to oxidation; and in order to show their extent, Table No. 9, derived from Tables II. and III. of Professor Long's report, has been prepared, in which the samples are grouped in such way as to give in juxtaposition, so far as possible, the same sample from the two places, the difference in time allowing for the flow from Bridgeport to Lockport.

The following are the means of all the analyses made from May to October inclusive (includes a number not given in the foregoing table.)

Place collected.	Date of collection.	Total solids.	Matter in suspension.	Nitrogen in nitrates.	Chlorine.	Hardness $CaCO_3$.	Free ammonia.	Albuminoid ammonia.	Oxygen consumed.
Bridgeport	1888	47.12	12.92	0.0	4.68	20.13	1.23	0.26	2.31
Lockport		43.12	6.98	0.0	4.61	20.77	1.08	0.20	1.62

The following are the means of a number of analyses made in January, February, and March, 1889. (The single analyses of these two series are not comparable in the same way as the summer series, from the fact that the samples were taken at both places on the same day.)

Place collected.	Date of collection.	Total solids.	Matter in suspension.	Nitrogen in nitrates.	Chlorine.	Hardness $CaCO_3$.	Free ammonia.	Albuminoid ammonia.	Oxygen consumed.
Bridgeport	Jan. to Mch., 1889	37.66	2.72	0.0	6.29	.....	0.89	0.28	2.65
Lockport		40.86	2.46	0.0	5.60	.....	0.81	0.25	2.28

The amount of purification attained appears from Table No. 9 to be quite slight, although dilution would undoubtedly assist the process somewhat. The indication of the table is, however, quite clear, that an ordinary stream receiving a large quantity of a moderately dilute sewage, of the average quality indicated by these tests at Lockport, can hardly be considered safe as a source of drinking-water for many miles beyond.

In a paper, Notes on some Cases of Drinking-Water and Disease, read by Professor William P. Mason, before the Chemical Section of the Franklin Institute, May 19, 1891, and to which we have already referred in Chapter I., page 10, some propositions are advanced in

regard to the process of self-purification taking place in the Illinois and Michigan canal, between Bridgeport and Lockport, which are of importance in connection with the present discussion.

The Law of Self-purification.

Professor Mason advances the proposition that the rate of purification varies directly as the amount of sewage contamination, and states

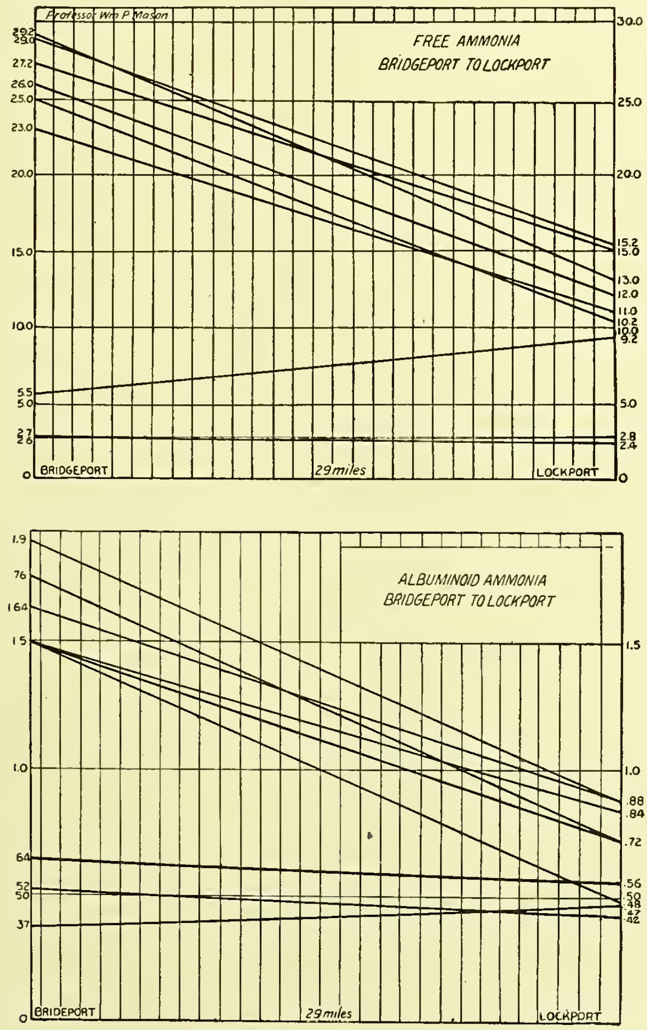


Fig. 3.—Decrease in Free and Albuminoid Ammonia in the Illinois and Michigan Canal from Bridgeport to Lockport, Ill.

that: "Given a stream with a certain amount of pollution, the per cent. of such pollution which must disappear per mile of flow will continually decrease as the stream flows on." In illustration of this proposition, Professor Mason submits a graphical exhibit of the results of a number of Professor Long's analyses (Fig. 3), showing the decrease in the free and albuminoid ammonias between Bridgeport and Lockport on certain dates. The following figures were used in preparing the diagrams:

	Parts per 1,000,000.			
	Free ammonia.		Albuminoid ammonia.	
	Bridgeport.	Lockport.	Bridgeport.	Lockport.
June 26	2.6	2.8	0.64	0.56
July 3	2.7	2.4	0.52	0.42
July 17	25.0	10.2	1.50	0.72
July 24	5.5	9.2	0.37	0.47
July 31	23.0	11.0	1.76	0.72
Aug. 7	26.0	12.0	1.50	0.48
Aug. 14	29.0	15.2	1.64	0.88
Aug. 21	27.2	15.0	1.50	0.84
Aug. 28	29.2	13.0	1.90	0.88

In regard to these figures and their significance, Professor Mason calls specific attention to the samples of July 3, which, with relatively low ammonias at both ends, show a loss of 11.2 per cent. of the free ammonia, and 19.3 per cent. of albuminoid ammonia; and also to the samples of August 28, where, with relatively high ammonias at both ends, the indicated losses are 55.5 per cent. free ammonia, and 53.7 per cent. albuminoid ammonia. Many other illustrations of the same law will be noted on examination of the results given in Table No. 9, in detail.

Stream Pollution in New York.

In New York State stream pollution has not, until the last two or three years, received the attention which its importance demands, although the Hudson and Mohawk rivers have been used as the sources of public water supplies for more than 20 years.

A few chemical analyses of the waters of these rivers may be found in the earlier water-works reports of some of the towns supplied, but altogether they furnish nothing of special value in studying questions of stream pollution. In 1873 Professor Charles F. Chandler made a number of analyses of the water of the Hudson river at Albany, and strongly recommended the river as a source of supply for that city. In 1885, after 12 years' use of it in accordance with that recommendation, some doubts arose as to the propriety of further use in view of

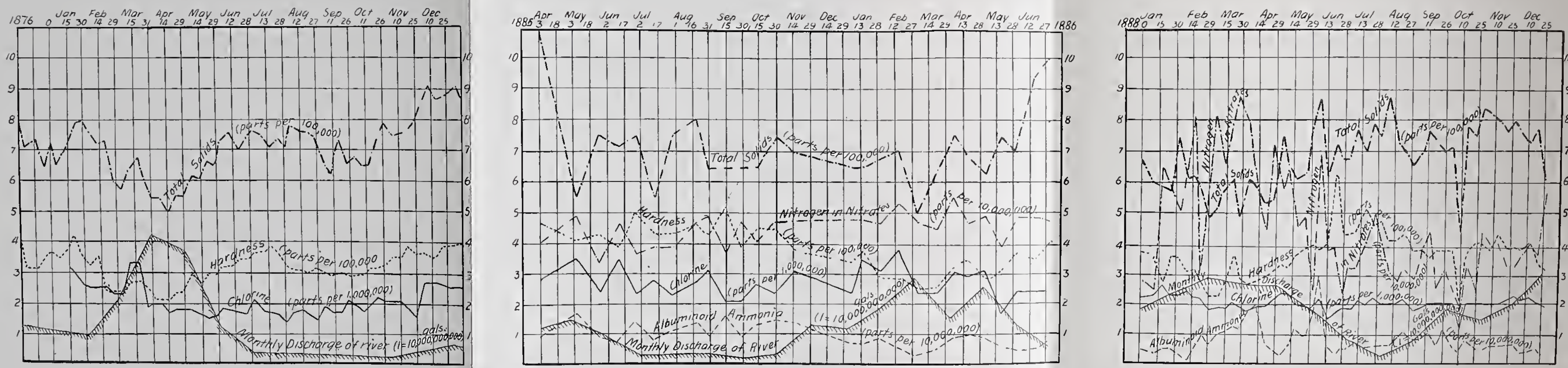


PLATE I. DIAGRAMS SHOWING CHEMICAL EXAMINATIONS OF CROTON WATER, 1876, 1885–6 AND 1888.

the constant and rapid increase of both sewage and manufacturing pollution. Professor Chandler again examined the Hudson river water, and a series of analyses of this and other American rivers may be found in his report to the Albany Water Commissioners of that year.

Protective Legislation in New York.

Notwithstanding the lack of organized study of stream pollution, the partial evils of it have been felt in various parts of New York State, especially in relation to preserving the purity of the public water supplies. This led to the passage in 1885 of an Act conferring upon the State Board of Health the power to protect from contamination, by suitable regulations, the water supplies of the State and their sources.

Early in that year the Executive Board of the city of Rochester caused to be made a detailed survey of all the various pollutions at and about Hemlock lake, the source of the domestic water supply of the city of Rochester. The information gained was used as the basis of rules and regulations, formulated by the State Board of Health under the act just referred to, for the protection of the Rochester supply. (See Appendices III. and IV.)

Similar regulations have since been made for the protection of the water supplies of the villages of Fredonia, Norwich, Cobleskill, and Oneonta; and the cities of Amsterdam, Mt. Vernon, and New York. The rules and regulations established at these several places are all modelled after the original Rochester rules, although in some cases modified to suit either the locality or to provide for special conditions. They may be found in detail in the several reports of the State Board of Health.

Furthermore, these rules have all been formulated to meet cases of pollution which were apparent to the unaided senses on inspection, and in regard to which it may be justly claimed that the pollutions were so flagrant that neither chemical nor biological studies were necessary to point out the necessity for improvement.

In connection with the establisment of the rules for the protection of the water-shed of the Croton river, an extended survey of the sources of pollution was made by Professor Charles C. Brown, C.E., whose report in the Ninth Annual of the State Board contains a compilation of all the chemical analyses of Croton water as made by the New York City Health Department for many years. As stated in the report a number of analyses are included in the tabulations which have never before been published. The tables include analyses from 1843 to 1888 inclusive.

In a brief discussion of these analyses by Professor Elwyn Waller, who, as chemist for the Metropolitan Board of Health, had made many of them, it is pointed out that as a whole they do not show any serious decrease in the quality of water from year to year. The fact is, however, clearly brought out, that the Croton water is considerably better some years than others.

The accompanying diagrams (Plate I.) from the report show some of the fluctuations.

In 1889 the State Board of Health began an extended study of the Hudson river with reference to pollution and allied questions. The Tenth and Eleventh Annual Reports (1890 and 1891) contain preliminary reports, and Professor Brown, who has charge of the work, promises an extended series of chemical and biological determinations for the Twelfth Report.

Classification of Streams with Reference to Pollution.

The foregoing essentially represents the present state of the information in relation to stream pollution in the United States. Studying it analytically, streams may be divided into five classes, namely:

(1) Streams which are the sources of public water supplies, and which are not polluted by either sewage or manufacturing wastes.

(2) Unpolluted streams which are not now the source of public water supplies, but which are likely to be so used in the future.

(3) Streams either polluted or unpolluted which are not the sources of public water supplies, and which are not likely to be so used in the future.

(4) Streams which are now the sources of public water supplies, and which are polluted with both sewage and manufacturing wastes.

(5) Streams which are now the sources of public water supplies, and which are polluted with manufacturing wastes only.

In regard to (1) it is clear that the thing to be done is to keep them in the same condition for all time to come. To this end, sharply cut legislative enactments ought in the majority of cases to prove sufficient. The New York State Act of 1885, with some modification in the way of increased powers for the executive sanitary authority, could be taken as a model on which to build.

For (2) it is equally clear that definite measures should be inaugurated for preserving them so far unpolluted that, when actually needed for water supplies, they may be so used without prejudice by reason of the previous occupation.

To this end each State needs some competent authority with a thorough knowledge of all the streams, ponds, lakes, etc., of the State.

In Massachusetts, as already seen, the State Board of Health is made the custodian of the inland waters, and given powers which enable it to properly decide each case on its merits. In New Jersey the last legislature had under consideration an act leading to State custody of inland waters, which, however, failed to pass.

For (3) it is probably permissible to use the streams as sewers and common drains, and the chief question to be considered is how much pollution any given stream will stand without becoming offensive to the senses or dangerous to health. In this connection it should be remembered that a sewage-polluted stream is not an entirely safe source of drinking-water for domestic animals.

The second question may properly be, What dilution of sewage in the stream is necessary in order to produce the best results in resolving it through the action of the biological forces? The standard of Mr. Hering, of 150 to 200 cubic feet per minute minimum flow per 1,000 persons contributing, is in the majority of cases probably too small a dilution for the best results. As a matter of judgment based on some laboratory experiments merely, for the present, a minimum flow of 300 cubic feet per minute per 1,000 people contributing may be taken, although subject to modification when more data are obtained.* The amount and kind of silt carried by any given stream, whether there are rapids or pools just below the point of discharge, are some of the physical features of the stream which will modify conclusions as to amount of dilution in any given case. If the stream is rapid flowing above the sewage outfall, carries large quantities of clay or other earthy matter in suspension, and is sluggish below, a relatively large amount of the suspended matter of the inflowing sewage may be deposited through the action of sedimentation in a very short distance.† On the other hand, with rapid flow below the point of discharge and little earthy matter in suspension, the insoluble portion of the sewage may be carried a long distance before there is much deposition. If rapids intervene the process of reduction will go on somewhat faster than when the rapid flow is merely that of a deep channel. All these points and many others will require taking into account before deciding any given case.

In regard to (4) there can be but one conclusion, the pollution should either be removed or their use as a public water supply discontinued. Probably the decision of any given case will depend to some extent upon the bearing of legal questions.

The decision of questions relating to (5) will be the most difficult of

* See Purification of Sewages by Microbes. Editorial discussion in Engineering, Oct. 7, 1892; reprinted in Eng. & Bldg. Rec'd, vol. xxvi., p. 380 (Nov. 12, 1892).

† In regard to the sanitary bearings of a partial purification by sedimentation only, see Chapter V., The Composition of Sewage Muds.

all. As pointed out in the chapter on The Legal Aspects of the Case, several of the States have, by the enactment of Mill Acts, apparently given legistative sanction to the ordinary pollution due to the use of streams as sites for manufacturing establishments. The development of manufacturing interests has led in Massachusetts to the well settled practice of temporary permissive pollution under State supervision, together with purification of streams by gradually removing sources of pollution, rather than by forcing an immediate abatement in every case ; the experience gained in that State indicates that an independent commission, empowered to consider each case on its merits, can more nearly satisfy the various conflicting interests than any other form of adjudication yet devised.

CHAPTER IV.

THE SELF-PURIFICATION OF RUNNING STREAMS, AND THE RATIONAL VIEW IN RELATION TO THE DISPOSAL OF SEWAGE BY DISCHARGE INTO TIDE-WATER.

In this chapter two questions are discussed which at first sight may be considered as possibly bearing no relation to each other. When, however, we take into account the action of biological forces it is found that they are in reality interdependent, a consideration which leads to their discussion together.

The Self-Purification of a Running Stream from the Biological Point of View.

It has been asserted at various times that a running stream so far tends to purify itself after a few miles' flow that the argument against drinking sewage-contaminated streams which have had an opportunity for several miles' flow is not founded in fact. So generally has this view been held that the Massachusetts legislature, in limiting the distance from the intake of a water supply, derived from a running stream, that sewage may be allowed to enter, has, in Chapter 80 of the General Statutes, fixed upon 20 miles. Beyond this distance, according to the legislature, there is no objection to polluting a stream with sewage, even though it is used as the source of drinking water. It would be interesting to know just how the legislature arrived at this limit of 20 miles. It is indeed true that under favorable conditions the tendency is toward self-purification, but the uncertainty as to how thoroughly the forces tending in that direction may act in any given case, is merely an enforcing of the views already expressed. By way of illustrating the recent views on the question of self-purification from the biological point of view, the following is given as a partial exhibit merely: *

Among the invertebrata there are certain classes of microscopic animals which, under favorable conditions of sufficiency of food supply, multiply in enormous numbers. As common representatives of these minute animals, we may mention; (1) certain of the filth infusorians, as for instance *Paramecium;* (2) *Hydra,* as the

* Discussion by Mr. Rafter of Dr. Chas. G. Currier's paper on Self-Purification of Flowing Water and the Influence of Polluted Water in the Causation of Disease, in Trans. Am. Soc. C. E., vol. xxiv., pp. 70-76.

typical representative of the order Hydroida; (3) certain of the Rotifera, of which *Lacinularia* and *Conochilus* may be cited as perhaps typical forms; (4) the numerous species of animals included in the entomostracan crustacea; (5) *Gammarus*, or the fresh-water shrimp; and (6) the larvæ of a number of water insects.

In comparison with bacteria the infusoria are creatures of vast size, even though some species are as small as $\frac{1}{1000}$ inch in length. *Paramecium aurelia*, a form found I believe almost invariably wherever putrefaction of animal matter is taking place in water, is an infusorial giant, mature individuals measuring as much as $\frac{1}{90}$ inch in length. *Paramecium bursaria*, however, is much smaller, about $\frac{1}{280}$ inch being the usual length.

In addition to *Paramecium*, there are a number of other ciliate infusorians, which are almost invariably found in water containing organic matter undergoing decay, and examinations made by the recently developed methods of biological enumeration, indicate that from twenty to fifty such forms may be found in every cubic centimetre of badly contaminated water; but whether any such numbers would be found in running streams, even though flowing slowly, I have had as yet no means of determining.

Any notice of the infusoria in relation to the self-purification of contaminated waters, would be incomplete without some reference to *Euglena* and the allied genera. In standing waters *Euglena viridis*, an infusorian of bright green color, is frequently present in such quantity as to impart a green color to the water. Its length varies from $\frac{1}{140}$ inch to $\frac{1}{600}$ inch. The vast quantities of *Euglena* which are met with under favorable conditions are sufficiently accounted for when we learn that it may multiply, not only by fission, or by the division of one individual into two, but it further multiplies by the "subdivision of the entire body substance into sporular elements, and by the development of independent germinal bodies out of the substance of the endoplast." *

Euglena is generally found in quantity in streams contaminated with sewage. *Hydra* is an animal of considerable size, frequently reaching a length, when fully extended, of nearly an inch. It is attached to water plants in quantity in stagnant waters, and voraciously devours everything coming within its reach.

Rotifers frequently develop in vast quantity in waters carrying large amounts of organic matter; and among such *Lacinularia socialis* may be taken as typical. This creature is usually attached to water plants along the margins of slowly running streams; and in favorite locations at certain seasons many hundred thousand colonies will be found in a limited space. The colonies are about $\frac{1}{5}$ inch in diameter, and frequently contain from fifty to one hundred individuals, each about $\frac{1}{12}$ inch in length. A single sprig of water plant has been found to support nearly one hundred colonies.

Another rotifer which may be mentioned is *Conochilus volvox*—a free-swimming, social form—with the colonies containing from seventy to one hundred individuals. The colonies are on an average $\frac{1}{20}$ inch in diameter, with the single members $\frac{1}{40}$ inch in length.

Probably the Entomostraca are of the animal forms the most efficient assistants in the self-purification of running streams. The vast numbers in which they develop, and the readiness with which they devour all sorts of filth, render them worthy of more extended study, from an economic point of view, than they have yet received.

As illustrating the forms especially worthy of attention, in this connection, may be mentioned *Daphnia*, *Ceriodaphnia*, *Cypris*, *Cyclops* and others. These are all found in waters containing decaying organic matters, and if the water is intended for domestic use, their presence in quantity may be taken as danger signals.† On the other hand, their presence in quantity may be taken to indicate a step in the process of self-purification of contaminated waters. As many as one thousand four hundred *Ceriodaphnias* have been counted in a single quart of such water,‡ and this number by no means exhausted the visible life in the sample.

A study of the Entomostraca, and observations of their immense fecundity and

* Kent: Manual of the Infusoria, page 379.

† Herrick: Crustacea of Minnesota.

‡ Herrick, *loc. cit.*

tendency to act as scavengers, led at an early day to singularly correct views as to the causation and spread of disease. Thus Otho Fredericus Müller, in his work on the Entomostraca, published in 1785, says: "The time is at hand when the causes of disease shall not only be sought after in the air, in our method of living, etc., but in the incautious use of waters often abounding in innumerable animalcules." The fertility of these little animals has already been referred to, and by way of illustrating it, reference may be made to Jurine's computation, that a single female *Cyclops quadricornis* might in one year have a progeny amounting to four billion, four hundred million.* The following are the average lengths of some of the animals of this group: *Daphnia*, $\frac{1}{10}$ inch; *Simocephalus*, $\frac{1}{8}$ inch; *Cyclops*, $\frac{1}{10}$ inch; and *Cypris*, $\frac{1}{12}$ inch. *Gammarus*, another crustacean of the order Amphipoda, is a denizen of sluggish-flowing, contaminated streams, where it may be frequently found in great quantity. This animal, when full grown, attains a length of $\frac{1}{2}$ inch. The larvæ of a number of insects pass their larval stage immersed in water, and among such the larva of the mosquito may easily take a high rank for large numbers.

The foregoing exhibits, in a very incomplete way, a few of the animals which assist in the self-purification of a running stream. The number of species which actually assist in such work is very great, and a mere enumeration of them would require considerable space. As to the definite part played by each species little can be said, as, with the exception of the Entomostraca, none of them have been studied in reference to their economic value in this direction. The exception noted in the case of the Entomostraca is a partial study made by Dr. H. C. Sorby, of England, a few years ago.

Enough can be gathered, even though we possess little definite knowledge, to justify saying that animals of the classes under consideration play a very important part in the so-called self-purification of streams. Minute plants may also be considered as assisting greatly in such work, but this part of the subject I leave untouched at this time.

The question of self-purification may, however, be somewhat simplified, if we consider just the distinction which marks the division line between animals and plants. The specific difference may be readily appreciated by considering that animals always require organized food; they seek those substances in which hydrogen, nitrogen, carbon, sulphur, etc., have been already assimilated into living forms, such living forms themselves being either animal or plant. Plants, on the other hand, have no power of assimilating organized food; they require rather the elements hydrogen, nitrogen, carbon, etc., in their primal state. In a general way, it may be said that this distinction holds good through the whole scale from the highest to the lowest. Indeed, when we come to deciding a difficult case, as for instance, whether a given form belongs to the Protophyta or the Protozoa, we take advantage of this distinction, and the natural line of study is to determine in which way food is taken by the unknown form.

A proper appreciation of this distinction will assist greatly in understanding the phenomena exhibited by streams in the process of self-purification. Thus we seem justified in concluding, that if contaminating organic matter in streams is to be reduced to an innocuous form, without the intervention of foul, odor-producing, putrefactive processes, it will be accomplished, in the earliest stages at any rate, by the assistance of animals rather than plants. Just how animals and plants assist in the process of self-purification, is finely exhibited by the paper of Dr. H. C. Sorby herewith appended, entitled, Detection of Sewage Contamination by the Use of the Microscope, and on the Purifying Action of Minute Animals and Plants.† Dr. Sorby says:

"By studying with the microscope the solid matters deposited from the waters of a river, the previous contamination with sewage can usually be detected without any considerable difficulty. If the amount be serious, the characteristic particles of human excrement can easily be seen; and if it is small and has been carried a long way by the current, it can usually be recognized by means of the

* Baird's British Entomostraca, page 190.

† Jour. Roy. Micr. Soc., 1884, pp. 988–991.

hairs of oats derived mainly from the droppings of horses, which resist decomposition for a long time, and are not consumed as food by minute animals. I, however, do not propose to enter into detail in connection with this part of my subject, but specially desire to call attention to the connection between the number of minute animals and plants and the character of the water in which they live, and also to their influence in removing organic impurities.

"For some time past I have been carefully ascertaining the number per gallon of different samples of river and sea water, of the various small animals which are large enough not to pass through a sieve, the meshes of which are about $\frac{1}{200}$ part of an inch in diameter. The amount of water used varies from ten gallons downward, according to the number present. By the arrangements used there is no important difficulty in carrying out the whole method in a satisfactory manner. I confine my remarks entirely to general mean results. The chief animals met with in fresh water are various Entomostraca, Rotifera, and the worm-like larvæ of insects. I find that the number per gallon and percentage relationships of these mark, in a most clear manner, changed conditions in the water, the discharge of a certain amount of sewage being indicated by an increase in the total number per gallon, or by an alteration in the relative numbers of the different kinds, or by both. All my remarks apply to the warm part of the year, and not to winter.

"It is known that Entomostraca will eat dead animal matter, though probably not entirely dependent on it. I have myself proved that they may be kept alive for many months by feeding them on human excrement, though they soon died without it. If the amount of food in any water is small, not many of such animals can obtain sufficient; but if it be abundant, they may multiply rapidly, since it is asserted that in one season a single female Cyclops may give rise to no less than four thousand millions of young. In stagnant muddy ponds, where food abounds, I have found an average of 200 per gallon. In the case of fairly pure rivers the total number of free-swimming animals is not more than 1 per gallon. I found, however, that where what may be called sewage was discharged into such water, the number per gallon rose to 27, and the percentage relationships between the different groups of Entomostraca were greatly changed. In the Thames at Crossness, at low water, the number was about 6 per gallon, which fell to 3 or 4 at Erith, and was reduced to less than 1 at Greenhithe.

"There is, however, a very decided limit to the increase of Entomostraca when the water of a river is rendered very impure by the discharge of too much sewage, probably because oxygen is deficient, and free sulphide of hydrogen present. Such water is often characterized by the great number of worm-like larvæ of insects. Thus, in the Don below Sheffield in summer, I found the number of Entomostraca per gallon only about one-third of what it is in pure waters; whilst, on the contrary, the number of worm-like larvæ were more than 1 per gallon.

"Now, if the minute free-swimming animals thus increase when a certain amount of sewage supplies them with ample food, it is quite obvious that they must have a most important influence in removing objectionable impurities. The number of excrements of Entomostraca in the recent mud of such rivers as the Thames is most surprising. In one specimen from Hammersmith I found that there were more than 20,000 per grain; and the average number at Erith in August, 1882, was about 7,000, which is equivalent to about 200,000 per gallon of water at half ebb, from the surface to the bottom. This enormous number must represent a very large amount of sewage material consumed as food; and though, as in the case of larger animals, a considerable part of their excrements no doubt consists of organic matter capable of putrefaction, yet there can be no less doubt that the amount entirely consumed in the life-processes of these animals is also great.

"As named above, I kept Cyclops alive for many months by feeding them on human excrement. It is thus easy to understand why, when they abound in the Thames, the relative amount of human excrement is very considerably less than in the winter, when their number must be much smaller. We thus appear to be led to the conclusion that when the amount of sewage discharged into a river is not too great, it furnishes food for a vast number of animals, which perform a most important part in removing it. On the contrary, if the discharge be too great, it may be injurious to them, and this process of purification may cease.

Possibly this explains why in certain cases a river which is usually unobjectionable may occasionally become offensive. It also seems to make it clear that the discharge of rather too much sewage may produce relatively very great and objectionable results.

"Though such comparatively large animals as Entomostraca may remove much putrefiable matter from a river, we cannot suppose that, except incidentally, they remove such very minute objects as disease-germs; but it would be a subject well worthy of investigation to ascertain whether the more minute infusoria can, and do, consume such germs as a portion of their food. If so, we should be able to understand how living bodies, which could resist any purely chemical action likely to be met with in a river, could be destroyed by the digestive process of minute animals. Hitherto, I have had no opportunity for examining this question critically, but have been able to learn certain facts, which at all events show that it is well worthy of further examination. It is only during the last month that I have paid special attention to the number of larger infusoria, and various other animals of similar type met with in the waters of rivers and the sea, which can be seen and be counted by means of a low magnifying power. At low water in the Medway above Chatham, in the first half of June, the average number per gallon has been about 7,000, but sometimes as many as 16,000. Their average size was about $\frac{1}{1000}$ inch. Possibly the number of still more minute forms may be equally great; but if we confine our attention to those observed, we cannot but conclude that their effect in removing organic matter must be very considerable. Judging from what occurs in the case of larger animals, those $\frac{1}{1000}$ of an inch in diameter may well be supposed to consume as food particles of the size of germs. Up to the present time I have, however, collected so few facts bearing on this question, that it must be regarded as a suggestion for future inquiry.

"So far I have referred exclusively to the effect of animal life. Minute plants play an important part in another way. The number per gallon of suspended diatoms, desmids, and confervoid algæ is, in some cases, most astonishing, and they must often produce more effect than the larger plants. As far as I have been able to ascertain, their number is, to some extent, related to the amount of material in the water suitable for their assimilation and growth. In the mud deposited from pure rivers their number is relatively small, but in the district of the Thames where the sewage is discharged, I found that in summer their number per grain of mud at half ebb-tide was about 400,000, which is equivalent to about 5,000,000 per gallon of water. This is two or three times as many as were found higher up or lower down the river, and out of all proportion more than in the case of fairly pure rivers like the Medway. Their effect in oxygenating the water must be very important, since when exposed to the light they decompose carbonic acid and give off oxygen, under circumstances most favorable for supplying the needs of animal life, and counteract the putrefactive decomposition so soon set up by minute fungi when oxygen is absent.

"Taking all the above facts into consideration, it appears to me that the removal of impurities from rivers is more of a biological than a chemical question; and that in all discussions of the subject it is most important to consider the action of minute animals and plants, which may be looked upon as being indirectly most powerful chemical agents."

The self-purification of streams, as pointed out by Dr. Percy Frankland and others, admits of discussion from two distinct points of view, namely, the chemico-physical and the biological. When discussed from the first the concensus of recent opinion is that dilution and sedimentation are the causes chiefly operative. From this point of view little remains to be said in addition to what has already been well said by others, and we may pass to the consideration in detail of a recently observed specific case of self-purification through the agency of the

biological forces.* We shall, however, consider the question from the purely physical point of view in the next chapter.

The Case of Beaver Dam Brook.

Beaver Dam brook, a tributary of Lake Cochituate, receives the water of the underdrain of the South Framingham separate sewerage system. The underdrain is laid at a lower level than the sewers and an analysis of the water flowing from it made before any sewage was turned into the sewers, in comparison with analyses made after, indicates that no leakage from the sewers takes place.†

Tables Nos. 10 and 11 give the results of a series of chemical and microscopical analyses made in August, 1890, as detailed in the Special Report, Part I., and also the Twenty-second Annual Report.

Table No. 10.—Analyses of Water from South Framingham Underdrain and from Beaver Dam Brook Above and Below, Made August 8, 1890.

(Parts per 100,000.)

Sample collected from	Chlorine.	Ammonia.			Nitrogen as		Serial number.
		Free.	Albuminoid.		Nitrates.	Nitrites.	
			Dissolved.	Suspended.			
Beaver Dam brook, above entrance of stream from underdrain	0.77	.0018	.0146	.0022	.0125	.0001	6381
Underdrain at outlet	3.62	.0648	.0058	.0000	.6000	.0036	6380
Brook, 300 feet below entrance of stream from underdrain	2.20	.0236	.0100	.0002	.2200	.0023	6382
Mouth of brook proper, one mile below underdrain	2.02	.0016	.0134	.0018	.2000	.0005	6383
Estuary of brook, 1,700 feet below its mouth	1.54	.0024	.0302	.0450	.0200	.0019	6384
Estuary of brook, 2,100 feet below its mouth	1.39	.[illegible]044	.0286	.0240	.0200	.0012	6385

On the date of these examinations it is stated that the brook was extremely low, its waters flowing sluggishly through a luxuriant growth of aquatic plants. After receiving the flow from the underdrain the relative proportion was, as further stated in the Special Report, 45 per cent. from the underdrain and 55 per cent. from the original water of the brook.

* For recent discussion of the self-purification of streams from the chemical point of view, see a paper by Dr. Percy F. Frankland on The Present State of Our Knowledge Concerning the Self-Purification of Rivers, read before the International Congress of Hygiene and Demography, 1891, in Eng. News, vol. xxvi., p. 218 (Sept. 5, 1891). The earlier Reports of the Mass. St. Bd. of Health contain a large amount of information from the purely chemical point of view, while in the very recent ones may be found the most of what we have in this country from the biological side of the question. Moreover, a discussion of pollution of streams involves largely their self-purification, and the chapter on Pollution, etc., contains an abridged account of some of the more important recent studies in this country from the chemical point of view, as for instance, the report of Mr. Wurtz on the pollution of the Passaic river, and the pollution of the Illinois and Michigan canal in Illinois, to which the reader is referred.

† Twenty-second An. Rept. Mass. St. Bd. Health, p. 149.

TABLE NO. 11.—RESULTS OF MICROSCOPICAL EXAMINATION OF SAMPLES NOS. 6,380 TO 6,385, AS PER PREVIOUS TABLE.

(Number of organisms per cubic centimetre.)

	1890.					
	Aug.	Aug.	Aug.	Aug.	Aug.	Aug.
Day of examination	9	9	9	9	9	9
Number of sample	6380	6381	6382	6383	6384	6385
PLANTS.						
Diatomaceæ	0	3	2	16	1,794	834
Melosira	0	1	0	7	0	0
Meridion	0	0	0	0	0	2
Navicula	0	2	pr.	5	2	0
Stephanodiscus	0	pr.	1	2	0	0
Synedra	0	0	1	2	1,792	832
Cyanophyceæ. Anabæna	0	0	0	0	460	328
Algæ	0	0	0	2	2,812	542
Chlorococcus	0	0	0	2	0	66
Cosmarium	0	0	0	0	12	0
Eudorina	0	0	0	0	84	4
Gonium	0	0	0	0	20	8
Pediastrum	0	0	0	0	8	0
Zoöspores	0	0	0	0	2,664	460
Scenedesmus	0	0	0	pr.	22	2
Staurastrum	0	0	0	0	2	2
Fungi. Crenothrix	400*	31	28	13	0	0
ANIMALS.						
Infusoria	0	0	0	pr.	92	12
Monas	0	0	0	pr.	0	0
Peridinium	0	0	0	pr.	80	4
Trachelomonas	0	0	0	0	0	8
Ciliated infusorian	0	0	0	0	12	0
Vermes	0	0	0	0	24	42
Anurea	0	0	0	0	0	24
Asplanchna	0	0	0	0	2	0
Monocerca	0	0	0	0	14	2
Polyarthra	0	0	0	0	4	2
Rotatorian ova	0	0	0	0	2	6
Triarthra	0	0	0	0	2	8
Total organisms	400	34	30	31	5,182	1,758

* Estimated.

Studying the results we note first of all the large amount of chlorine in the water of the underdrain, which is taken as meaning that it derives a portion of its water from the cesspools in use before the sewers were built and which are still in use in many instances. Even if the cesspools had all been abandoned immediately on the completion of the sewerage system in 1889 their effect could hardly have failed to be manifest for some time after. The water issuing from the mouth of the underdrain is clear and colorless and contains considerable *Crenothrix*, which rapidly deposits in the sluggish current of the open channel. The water of the brook itself above the mouth of the underdrain also contains a small amount of *Crenothrix*, as shown by the

microscopical analysis No. 6,381. As the flow proceeds down the brook, the analyses show a progressive change, and comparison of the successive stages of development of the plant life with the changes in quantity of the ammonias and nitrates, indicates the nature of the changes in the organic matter which are taking place. The importance of distinguishing between the suspended and dissolved albuminoid ammonia is also clearly brought out by these analyses.

September 5 and 10, 1889, samples taken from the lower part of the Beaver Dam brook estuary were examined microscopically by Mr. Rafter. At that time the plant life was chiefly *Zoöspores*, there being present on September 25, 2,442 per cubic centimetre, with 52 *Diatomaceæ;* and on September 10, 2,018 *Zoöspores* and 14 *Diatomaceæ* per cubic centimetre. Heavy rains during the preceding summer had kept the stream at an abundant flow. We may conclude, therefore, that the results obtained in August, 1890, were not exceptional, but that, on the contrary, in this case the biological forces are constantly at work in effecting a purification. This special case has been further discussed by Frederick P. Stearns, M. Am. Soc. C. E., in the Special Report of the Massachusetts State Board of Health, Part I., and the reader is accordingly referred to that discussion for additional detail in regard to it.

Before concluding the subject it may, however, be properly pointed out that this example is not quite the same as the problem of purification of a river polluted by raw sewage, as discussed by Dr. Sorby. We have in this case rather an incomplete reduction of the organic matter to the state of nitrates through the operation of partial soil filtration, and probably in such cases the farther changes in the nitrogen will take place through the influence of plants rather than animals. It may be pointed out, moreover, that mineral nitrates usually act as stimulants of an abundant algal life.

THE MANURIAL CONSTITUENTS OF SEWAGE.

There is a popular impression that great quantities of valuable manure annually go to waste in the sewage of our large cities and towns, and much ingenuity has been expended in attempts to utilize the manurial elements of sewage. None of the various projects looking toward such realization have thus far been successful from a commercial point of view, and, however hard it may be for those who have preconceived opinions on the subject to change their views, it must still be concluded that, in the present state of the applied sciences, anything like a general utilization of the manurial constituents of sewage at a commercial profit is apparently impossible. A consideration of the amount of the manurial constituents in comparison with the

amount of water carrying the sewage serves at once to emphasize the difficulties of the problem. Thus the average of total dry matter in a ton of sewage from an ordinary English town is from two to three pounds, while in American cities, where the use of water is greater than in the English towns, the amount is much less. Professor W. R. Nichols having found it to be only about one pound per ton in the sewage of Boston in the year 1872.

The following table, No. 12, which gives the mean results of a number of analyses, will serve to show the amount of matter actually present in the sewage of a number of cities: *

TABLE NO. 12.—CONSTITUENTS OF SEWAGE.

	Dissolved matter.	Suspended matter.	Total dry matter.
2,000 lbs. Boston sewage	1.179	0.747	1.926
2,000 lbs. Worcester sewage	0.507	0.423	0.930
2,000 lbs. Berlin sewage	1.578	0.102	1.680
2,000 lbs. of sewage, average 50 English towns	1.444	0.894	2.338
Organic	0.276	0.603	0.879
Inorganic	1.146	0.778	1.924
Sum	1.422	1.381	2.803

Of the fertilizing matters in sewage the nitrogen compounds are the most important, but their amount is very small, as little as 0.04 and 0.05 pound in the Worcester and Boston sewage, as determined by Professor Nichols.

MONEY VALUE OF SEWAGE.

From such data as the foregoing it has been estimated that the sewage of English cities may contain from one to four cents' worth of fertilizing matter per ton, while a ton of the Boston sewage as indicated by these analyses will contain say one cent's worth of manure. †

The conclusion from the foregoing cursory examination is that the valuable constituents of sewage are so diluted that the cost of extracting them by any known process is, on the whole, equal to, or in some cases even greater than the value of the material after it is extracted.

FALLACY OF THE ARGUMENT.

The argument as to the fallacy of attempting to utilize sewage at a commercial profit has been put very appropriately by a number of writers, as, for instance, Professor Anderson, who says it would be

* Storer's Agriculture, vol. ii., p. 286.

† For discussion of this phase of the question in detail see paper, Sewerage; Sewage; The pollution of Streams; The water supply of towns, in the 4th An. Rept. Mass. St. Bd. Health (1872). By Nichols and Derby.

about as reasonable to expect farmers to manure their land with the smoke of cities as with sewage, for, as everyone knows, enormous quantities of ammonia must be lost in the aggregate from cities where domestic fires are fed with soft coal. But precisely as it is with smoke so it is with sewage; that is to say, the fluid is so very dilute that it cannot be put to use.

David Forbes, also, in replying to calculations based upon the assumption that the excrement of each inhabitant of a city represents a value of several dollars a year, argued that it would be equally correct to maintain that a barrel of water into which a bottle of brandy had been poured would be worth as much as the original brandy.*

Professor Storer cites, also, another very striking illustration of a valuable substance so diluted as not to be worth the cost of collecting: The city of Philadelphia stands on an extensive bed of clay which contains a pound of gold for every 1,224,000 pounds of clay, and, it appears evident that this bed of clay contains, within the corporate limits of the city, at least $1,000,000,000 worth of gold. Except as a matter of scientific interest no one has ever dreamed of extracting gold from this Philadelphia clay. It can be got, with infinitely less trouble, from places where it is more abundant; and in this, as in everything else, the cost of getting the thing depends upon the amount of labor of some sort that must be expended. It is precisely so with sewage utilization, and the sooner a clear appreciation of this fact is generally disseminated, probably the sooner will the question of sewage purification be placed on a thoroughly practical basis. At the present time agriculturists can get commercial fertilizers cheaper than the manurial elements of sewage can be utilized, and, so long as this proposition remains true, it is idle to talk of making sewage utilization, except under favorable circumstances, a commercial success. For a presentation of the manurial constituents of domestic sewage in detail, with theoretical commercial values, see Chapter VIII., on General Data of Sewage Disposal.

The Right Way to Approach the Problem.

With this understanding, the problem of sewage purification is naturally approached from a different point of view from what it would be if we expected to realize commercial returns, either by utilization in broad irrigation or by the sale of a manure from the sludge, resulting from processes of partial chemical purification. Experience abroad has apparently settled both these questions, so we can approach the subject in this country in a somewhat more rational way than has characterized a large portion of the early discussion abroad. A full

* Storer's Agriculture, vol. ii., p. 288.

appreciation of the fact, on the part of the public, that ordinarily little commercial profit can be realized from sewage utilization, is of considerable importance in the beginning of sewage purification processes on an extended scale in this country. Such appreciation enables sanitarians and others interested in the improvement of the public health to insist upon sewage purification as a right which one community or individual owes to another, independent of the question of commercial profit; it further prevents the failure of executed projects which are successful in effecting a purification, but which do not return a commercial profit on the capital invested; again, it removes the motive for bolstering up projects, which, while inefficient in purification, are still operated at a commercial profit; it puts the whole subject, in short, on a scientific basis, in which the health of communities is placed first, and questions relating to commercial utilization are kept in the background, as of secondary importance only.

In advancing the foregoing views it is not intended to assert either that broad irrigation may not be a successful way of both purifying and utilizing sewage when the proper conditions obtain, or that the sludge from a chemical process is not worth something for manure. It is desired merely to point out that in the present understanding of things, commercial utilization of sewage is, so far as this country is concerned, properly subordinate to the more important question of thorough purification.

Moreover, in considering this phase of the question of sewage purification, we should not lose sight of the fact that, independently of the manurial ingredients of sewage, it has, when not applied in too excessive quantities, a distinct value for purposes of irrigation. While, therefore, the preceding propositions are fundamentally true, it may be still stated that many cases will undoubtedly arise in practice in which broad irrigation may be an exceedingly valuable method of sewage purification; and it is in this latter view that the subject has been discussed at length in Chapters XII. and XIII., following.

Sewage Disposal Works Not Properly Subject to Franchise.

As a corollary to the foregoing, it may be concluded that, generally speaking, sewage disposal works are not properly subject to franchise by private companies. The interests to be served are so important, and the effect of neglecting to render proper service so serious and far-reaching, that the commercial spirit should be absolutely eliminated from everything relating to sewage disposal. The problem has generally been regarded in this light, as is shown by the fact that only a few municipalities, mostly small ones, have granted sewerage franchises, New Orleans being the only large city which has taken such action.

Disposal into Tide-Water.

Again it may be further concluded that where the conditions clearly indicate disposal into tide-water as the rational course of procedure there is no valid argument to be urged against such disposition. The view of twenty years ago that turning sewage into the ocean was a drain upon national wealth may be considered as fairly met by what has already been offered in reference to cost of utilization. There is, moreover, another line of argument substantiating the same conclusion from an entirely different point of view. We have already seen that when the amount of sewage per unit volume of water is not too large, the entomostracan crustacea multiply in enormous numbers. The Entomostraca are further the favorite food of the carnivorous fishes,* and while it has been the experience in Boston harbor and elsewhere that too much sewage per unit of volume drove the fish away from the vicinity of sewage outfalls, nevertheless the increase in Entomostraca and their utilization for food of fish at points somewhat removed from the centers of sewage pollution may be considered a practical utilization of sewage, and a direct return therefrom to the total stock of national wealth. To secure this return in the largest degree, it is still essential that certain general principles be observed in relation to the quantity and quality of the sewage discharge. In the first place the sewerage system should be so designed as to deliver the sewage into tide-water while perfectly fresh, and to this end tidal discharge sewerage systems need to be self-cleansing, so far as is possible, in order to reduce sewage putrefaction to a minimum. Again the discharge at any given point should be, if possible, relatively small. Any tendency to the production of either an effluvium nuisance or of a foul beach line may be taken as evidence that the limit of quantity at any given point has been exceeded. We arrive, therefore, at the conclusion that for practical utilization of sewage as food for fish, the concentration of large quantities of sewage and the discharge of the same into tide-water at the single point is, generally speaking, undesirable. By discharging the sewage at a number of points, each far enough removed from the other to insure the proper dilution which has been pointed out by Dr. Sorby and others as necessary for the development of the maximum quantity of minute animal life, the best results will be secured.

Disposal into Fresh Water.

The same conclusion holds good when for any reason it may be considered either necessary or desirable to discharge large quantities of

* See the various Reports of the United States Fish Commission.

sewage into bodies of fresh water.* The correct principle governing such discharge has been recognized by the Milwaukee Special Commission, appointed "to prepare and present plans and estimates for the completion of works for the collection and final disposal of the sewage of the city, and for the permanent location of the intake for the water

* In this country the most important studies thus far made of the relation of the minute life in water to fish life, are those of Professor S. A. Forbes, of the Illinois State Lab. of Nat. History. Beginning in 1877, Professor Forbes has published in the Bulletin of the Laboratory to date the following:

(1) The Food of Illinois Fishes, vol. i., No. 2, pp. 71-89.
(2) The Food of Fishes, No. 3, pp. 18-65.
(3) On the Food of Young Fishes, No. 3, pp. 66-79.
(4) The Food of the Smaller Fresh Water Fishes, No. 6, pp. 65-94.
(5) The First Food of the Common White Fish, No. 6, pp. 95-109.
(6) Studies of the Food of Fresh Water Fishes, vol. ii., art. vii., pp. 433-473.
(7) On the Food Relations of Fresh Water Fishes: a Summary and Discussion, art. viii., pp. 474-538.

In these several papers Professor Forbes has discussed nearly every phase of the question of food for fishes, and pointed out in many cases the specific food of different species of fish.

The great economic value of the Entomostraca is strongly brought out in these papers, and especially as food for young fish. In the paper on The First Food of the Common White Fish, an account is given of the result of examining the stomach contents of over 100 young fish. After giving the data derived from these examinations in detail, Professor Forbes says:—

> * * * We are compelled to conclude that the earliest food of the white fish consists almost wholly of the smaller species of Entomostraca occurring in the lake, since the other elements in their alimentary canals were evidently either taken accidentally, or else appeared in such trivial quantity as to contribute nothing of importance to their support.

In the paper on The Food of the Smaller Fresh Water Fishes it is further shown that the chief food of the young of the family Cyprinidæ (popularly minnows) which embraces by far the larger part of the smaller fishes, is composed of such vegetable elements as filaments of *Spirogyra* and other filamentous algæ, cells of *Cosmarium* and *Closterium* among the desmids, together with *Cymatopleura* and other diatoms. Among representatives of the animal kingdom *Euglena* was found to be an important item, as was also Bosmina, an Entomostracan.

Summarizing the food of the young of this family, Professor Forbes says:

> * * * we may conclude that the young Cyprinidæ draw almost indiscriminately for their food supply upon Protozoa, Algæ, and Entomostraca.
> The fish of the family Cyprinidæ are of economic interest because of furnishing an important part of the food supply of larger species.

No. (7) of the foregoing list is the concluding number of the series of papers on the food of fish and in it Professor Forbes has presented a number of highly important facts and conclusions of interest in the present discussion, as for instance a statement in detail of the percentage of the various minute plants and animals found in the food of different species of young fish. Thus, the food of young perch consists of 92 per cent. of Entomostraca, while the food of young bass, sunfishes, and pickerel consists of from 50 to 70 per cent. of Entomostraca.

Young suckers prefer a diet of Entomostraca, Rotifers, Infusoria, and unicellular Algæ, while young catfish apparently dine only on Entromostraca and Chironomus larvæ.

Recapitulating, Professor Forbes says:

> I find that, taking together the young of all the genera studied, considering each genus as a unit, and combining the minute dipterous larvæ with the Entomostraca as having essentially the same relation, about seventy-five per cent. of the food taken by young fishes of all descriptions is made up of these elements.

The conclusions of this paper are based upon a study of 1,221 fishes obtained from the waters of Illinois at intervals from 1876 to 1887, and in various months from April to November; they represented eighty-seven species, sixty-three genera and twenty-five families. A detailed recapitulation of data showing the number of examples of each species of fish in which a given food element was detected, appears at the end of the paper.

supply of the city." In the report submitted to the Mayor and Commissioners of Public Debt in 1889, this commission presented plans providing for the discharge of the sewage of the city into Lake Michigan, at a large number of different points, instead of one, and while the reasons assigned in the report for this arrangement are not entirely satisfactory from the present point of view, they may nevertheless be considered sufficient for the particular case. The Commissioners say:*

At the lake end of the outfall sewer, a terminal basin is to be built. From this basin, two iron pipes, each 56 inches in diameter, are to discharge the sewage into the lake.

These pipes are to be of sufficient capacity to carry all of the dry weather sewage, and a portion of the storm water. The basin is to be so arranged that the surplus of storm water is discharged over a weir, directly into the lake.

* * * * * * * *

In order to dilute the sewage to a high degree in the shortest possible time, and thus promote the rapid oxidation of the organic matter contained in it, the discharge from the 56-inch pipe is to be through eleven branch connections, placed about three hundred feet apart; the first discharge branch being placed about three thousand feet from shore. The branches are to be 17 inches diameter, and reduced, at the points of discharge, that the same quantity of sewage will be delivered by each branch. The size of the main pipes is to be diminished, after passing each branch, so that the velocity of flow may be maintained about the same throughout the entire length.

The branches are to be placed in a vertical position, discharging about five feet above the bottom of the lake, and to be secured in their position by piles, or riprap filling.

For a distance of 1,000 feet from its outer end, the main pipe is to be laid on piles, so as to bring the discharge about 6 feet above the bottom of the lake. Any road detritus, or other material that may at long intervals accumulate at the mouth of the pipe, can be removed by dredging.

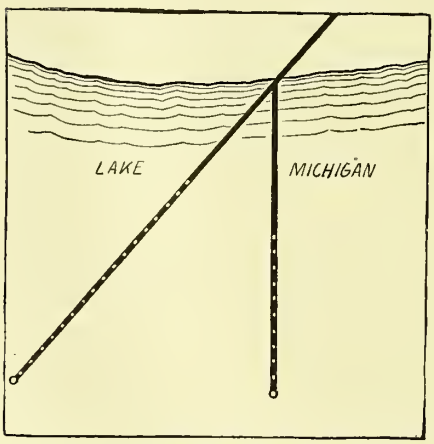


Fig. 4.—Proposed Multiple Discharge Outlet Sewer at Milwaukee, Wis.

Fig. 4, from the Commission's Report, illustrates the proposed method of discharge.

The question of practical utilization of sewage as food for fish has also recently received considerable attention in England, and a number of interesting and valuable conclusions have been drawn. In the *Agricultural Gazette*, Sir J. B. Lawes, of Rothamsted, discusses the subject at length,† and cites a number of facts, the real significance of which has not, so far as the authors are aware, been previously clearly pointed out.

* Report of the Commission of Engineers on the Collection and Final Disposal of the Sewage and on the Water Supply, of the City of Milwaukee, 1889.

† See Colonel Waring's Sewerage and Land Drainage, pp. 231–232, for an extended extract.

Dr. Sorby's results in relation to the number of entomostraca in rivers, apply entirely to fresh-water forms, but the marine entomostraca are quite as numerous as the fresh water,* and we may assume that what is true of the one is equally true of the other.

The Legitimate Conclusion..

The minute forms of animal life are thus seen to be powerful agents in the self-purification of sewage-polluted waters, but the conclusion which has been drawn that, therefore, sewage-polluted streams are, after a few miles' flow, fitted through the action of such and other natural agencies for drinking, is not wholly justified by the present state of knowledge of the subject as a whole.

Along with our knowledge of the purifying action of the minute animals and plants has grown up a more definite knowledge of the causation of typhoid fever, cholera, and the other water-borne communicable diseases; and before it can be positively affirmed that a sewage-polluted stream is safe for drinking after a few miles' flow, it must be shown so definitely as to be beyond question by those whose special studies have fitted them for intelligent judgment, that the purifying agencies have practically eliminated the germs of the water-borne communicable diseases. Until such showing is clearly made, the proposition that crude sewage ought not to be turned into running streams, ponds, lakes, or other bodies of water, which either are, or may be, the sources of water-supplies, must be considered as holding good.

The Rational View of Disposal into Tide-Water.

We may conclude from this brief discussion that the question of rational disposal of sewage in tide-water is not only transcendently important to the many large cities on the seaboard, but that its magnitude is such as to render it difficult to reach a successful solution except by studies of wide range. An investigation by the General Government might therefore be appropriate, by reason of its involving the broad question of national waste versus ultimate economic conser-

* See (1) Baird's British Entomostraca.
(2) Dana's Crustacea of the Wilkes Exploring Expedition.
(3) Reports of the United States Fish Commission.
(4) Catalogue of the Specimens of Amphipodous Crustacea in the Collection of the British Museum.
(5) Brady's (a) British Oceanic Entomostraca; (b) Copepoda of the Challenger Expedition; and (c) Ostracoda of the Challenger Expedition.
(6) Brooks' Stomatopoda of the Challenger Expedition.
(7) Sars', (a) Cumacea of the Challenger Expedition; (b) Phyllocrida of the Challenger Expedition; and (c) Schizopoda of the Challenger Expedition.

vation.* As the matter stands, it may be asserted that there are absolutely no detailed data proving that sewage disposal in tide-water, under proper conditions, is in any way a waste of raw material.

In regard to purification of sewage by intermittent filtration, in such manner as to convert the bulk of the organic matter into soluble mineral nitrates, we are equally unable to affirm that there is here, in any sense, a waste of raw material. The nitrates, when flowing into streams, become the chief nourishment of an abundant cryptogamic life, which is again devoured by sponges, rhizopods, infusoria, and other Protozoa.†

Protozoa again, with a certain portion of the Cryptogams, are eaten by higher minute forms, until in the universal round we may finally find our sewage utilized by an increase in the piscatorial life of the fresh water inland streams. Moreover, it must be urged that the mere fact of our present inability to control these cycles is no argument against the truth of the view here advanced; such inability can only be taken as merely indicating the dearth of definite data in this direction.

* Such a study would seem to be in line with the work of the Fish Commission, and could be made by it without great expense.

† In reference to the food supplies of the Protozoa and classes immediately higher in the scale, it may be said: (1) that the chief food of fresh-water sponge is largely minute spores of algæ, though the sponge when growing, attached to a fixed place, cannot be considered as having much power of selection, and may, therefore, at times, take into its organization animal foods also. It apparently receives and digests anything which the flowing waters in which it is usually found may bring to it. The proof that algæ may be considered the chief food is derived from the fact that sponge apparently prefers localities where algæ spores are more abundant than infusoria. (2) Rhizopods, according to Professor Leidy, chiefly devour desmids, diatoms, and other minute algæ; and many of the elegant illustrations in his Fresh-Water Rhizopods of North America show the little animals in the very act of ingesting the various forms of plants which they apparently prefer. The recurrence of examples of this character leads to the conclusion that the rhizopods, unlike the sponge, have some power of selection and are able to exercise a degree of preference. (3) The infusoria, probably, take whatever comes in their way; the motions of the flagella and cilia of the different classes set the water in the vicinity of each individual in motion, and whatever is within reach, and not of too large a size to enter the oral aperture, is received, digested, and the refuse excreted the same as with other animals. Some species, apparently, prefer decaying animal matter (*Paramecium*, *Coleps*, etc.), and are usually found in vast quantities wherever such decay is taking place. Others (*Trachelocerea*, etc.), are found among vegetable débris, filaments of decaying algæ, etc. As with sponge and rhizopods, algæ spores are probably a large portion of the food of the infusoria. (4) In the next higher class of animals we find hydra, which is essentially a carnivorous feeder, worms, entomostraca, and other animals, falling an easy prey whenever they venture within reach of its moving tentacles. (5) Polyzoa feed mostly on desmids, etc., with decayed vegetable matter, and have a finger, or tongue-like organ, stretching over the mouth, which enables them to exercise some selection of the food coming within reach. They sometimes dine on rotifers. (6) Rotifers are like infusoria, in that the rotating apparatus, from which they derive their name, is in rapid motion when feeding, and brings into the capacious mouth—characterizing most of the species—whatever happens to be in the vicinity, although some power of selection may be observed. The literature of the food-supplies of the minute animals is still comparatively scarce. The classificatory tendencies of nearly all the writers on this branch of zoölogy has thus far mostly obscured the biological side of the subject, and with the broader views of the present day we must, to some extent, traverse ground already gone over, in order to supply

In the discussions of this question which have taken place in England, it has been asserted* that the argument in reference to increase and decrease of fish by reason of either sufficiency or insufficiency of food supply is not valid, because "probably all the great sea fisheries are inexhaustible." In reference thereto it is answered that twenty years ago it was generally held in this country that the buffalo of the Western plains were inexhaustible, and to any one, who, traversing the plains at that period, saw the immense herds, it did appear plausible to say that no efforts which man could make would have any special effect upon such countless numbers. Nevertheless there are to-day less than 1,000 buffalo within the limits of the United States, and this extraordinary extermination has all occurred in 20 years. Again sixty years ago it was not unusual to find large schools of whales just outside New York and Boston harbors, and many successful whaling voyages were made to portions of the sea where now whales are scarcely ever seen. Again the rapid exhaustion of oyster beds is within the experience of everyone engaged in the oyster fishery. Many other similar illustrative examples could be cited, but the foregoing is considered sufficient to indicate that it is quite possible to conceive of a great ocean fishing interest either seriously injured or even actually driven to other localities by systematic catching in excess of the natural increase; and that this has frequently happened in inland rivers and lakes is attested by the presence on the statute books of every State of protective laws. We may, therefore, fairly conclude that anything which tends to increase the food supply of fish must be looked upon as assisting in conserving the fisheries, through the operation of the natural law that sufficiency of food supply is one of the forces accelerating natural increase.

material deficiencies in the information. The following works may be consulted for hints merely; a complete systematic treatise still remains to be written:

Baird, British Entomostraca.
Carpenter, The Microscope and its Revelations.
Cooke, Ponds and Ditches.
Gosse, Evenings with the Microscope.
Herrick, Crustacea of Minnesota.
Hudson and Gosse, The Rotifera or Wheel Animalcules.
Kent, Manual of the Infusoria.
Leidy, Fresh Water Rhizopods of North America.
Report of Commissioners on Investigation of the Water-Supply of the city of Boston (1883.)
Slack, Marvels of Pond Life.
Taylor, The Aquarium.
Tiemann and Gärtner, Untersuchung des Wassers, etc.

In addition, the various journals of Microscopy and Zoölogy contain notes and observations of more or less interest.

* Corfield, Treatment and Utilization of Sewage, 3d ed., pp. 303–305.

CHAPTER V.

THE COMPOSITION OF SEWAGE MUDS.

THE CONDITIONS FAVORABLE TO SEDIMENTATION.

THE fact that a stream which is visibly polluted at one point may be clear and limpid only a few miles below is probably within the experience of every person who has paid any attention to the pollution and self-purification of streams. Widely varying opinions have been expressed as to the fate of the polluting matter, which, to the unaided senses, appears to have been removed from the flowing water. On the one hand, it has been claimed that an absolute destruction, through the action of either oxidation or of purely biological forces, has taken place, while, on the other, it is asserted that the apparent purity of the flowing water is due entirely to sedimentation, according to which the organic matter may still be found in a nearly unchanged form at the bottom. Probably the real truth is that all these several methods of self-purification may be operative in different streams, although undoubtedly sedimentation is, where the conditions are favorable, likely to be a leading cause. Relative to the conditions favorable for sedimentation, they may be stated in a few words generally as produced by the presence in the water of some substance which naturally tends to assist sedimentation. For instance, a stream carrying a considerable quantity of clay in suspension is likely to free itself of sewage by sedimentation more quickly than one in which the water is, under normal conditions, entirely free of earthy matter in suspension. In a stream where the conditions are unfavorable for rapid sedimentation we may expect to find of more importance the purifying effect of such minute animals as actually consume in their life processes a portion of the polluting matter; while, in a rapid flowing stream, where the water tumbles over falls and cascades and flows down rapids, there may be a considerable degree of self-purification through the operation of the chemical process of oxidation purely. The self-purification of a stream may be effected, then, by either mechanical, biological, or chemical agencies, or by all of them acting in conjunction, and to which to ascribe the self-purification in any case can only be determined by a careful study of the attendant circumstances. For present purposes we will consider the case of a stream in which an apparent self-purification

from sewage inflow is obtained within a short distance through the action of sedimentation. In doing this we will not concern ourselves as to just what agency is effective in producing sedimentation, but will merely assume such rapid action that a stream of moderate volume in ordinary stages frees itself of the visible evidence of a gross sewage pollution in the course of a sluggish flow of a few miles. We will further assume that the mean flood flow of the stream is at least 100 to 200 times the ordinary flow at the season of low water, from which it results that the velocity through a given cross-section will be from 100 to 200 times as great in flood flow as in low water. Under these conditions, it is clear that the deposited matter of a long period of low water may be swept along for an indefinite distance by the first flood flow, and, if we assume, as we safely may, that the organic matter of the deposited sewage has undergone little change, it follows that water supplies taken from the stream many miles below will be, in times of flood, as thoroughly subject to the deleterious influence of the sewage discharge as though water were drawn from that reach of the stream in which the most of the sedimentation takes place.* To appreciate the importance of this conclusion, we have only to consider that, in flashy mountain streams, the accumulated deposits of months may be swept along for many miles in a day.

Macadam's Study of the Water of the Leith.

Considering the importance of this phase of the self-purification of running streams comparatively few detailed studies have been made, but the few fully substantiate the view that sewage sediments retain their dangerous character for long periods of time.

Of such studies, one of the first is that of the water of Leith made by Macadam in 1864, and given at length in the Third Report of the Sewage of Towns Commission.†

The Leith is a comparatively small stream, which, at the time of Macadam's report, received the sewage of about 100,000 people in the neighboring towns of Edinburgh and Leith. The accumulation of the sediment of this sewage in the mill dam and pools of the stream and in the harbor of Leith, had led to the production of a most disgusting nuisance. In many places the banks of sewage mud were several feet in depth, and analyses of samples from different parts of the stream

* For discussion of the conditions obtaining on the bottom of a stream in which sedimentation has been effective see paper, On the Amount of Dissolved Oxygen in Waters of Ponds and Reservoirs at different depths, by Dr. Thomas M. Drown, 22d An. Rept. Mass. St. Bd. Health (1891), pp. 373–381; the greater part of this paper was also published in Eng. News, vol. xxviii. (1892), pp. 309–10.

† On the Contamination of the Water of Leith by the sewage of Edinburgh and Leith. By Stevenson Macadam, Ph.D. etc. 3d Rept. Sew. T. Com., Appendix No. 5.

showed, in some cases, amounts of organic matter as high as 55, 66, and in one case, of 82 per cent. The means of one series of four samples of mud from the stream was, organic matter, 48.1 per cent., and earthy matter, 51.9 per cent. The same series showed a mean of 1.63 per cent. of nitrogen. Another series of eight samples gave as a mean, organic matter, 43.7 per cent., earthy matter, 56.3 per cent., and nitrogen, 1.14 per cent. of the whole. A series of 12 samples from the harbor, where more or less sand is brought in with the tide, gave a mean of organic matter 28.3 per cent., earthy matter, 71.7 per cent. and nitrogen, 0.64 per cent. Macadam's investigations were before the days of bacteriological examinations, and we are accordingly left in the dark as to what would now be a very important division of such a study; but he recognized the importance of a knowledge of the larger microscopical forms, and notes the presence of masses of infusoria belonging to the family Vorticellidæ, including the genera *Vorticella, Carchesium, Zoothamnium* and *Epistylis*. *Paramecium* and *Euglena* were also abundant.

Macadam's results have been verified by a number of studies of the muds of the Thames river, the more recent of which are those of W. J. Dibdin, made in 1879–80, and 1882–83. Mr. Dibdin found in some samples from sewage of 24 hours as high as 57.4 per cent. of volatile matter in dried mud, with nitrogen of the dried mud amounting to 3.3 per cent. and nitrogen of the dried volatile matter 5.75 per cent. The phosphoric acid of the dried mud in the same sample was 0.8 of one per cent. The means of the samples of mud taken at different points are, however, considerably lower than this.

The net result, not only of Macadam's but of the more recent investigations, is to emphasize the statement already made, that usually the effect of a flood flow would be to actually increase temporarily the pollution at points far below where sedimentation takes place.

Dr. Beale's Study of Thames Muds.

After Macadam, nothing so interesting appeared until the publication by Dr. Beale of a paper on The Constitutents of Sewage in the Mud of the Thames, in 1884,* in which are detailed the results of a microscopical study of 25 samples of Thames mud taken from various banks between Gravesend and Chelsea, the observations relating chiefly to the demonstration by microscopical investigation of the existence in sewage muds, which have been deposited a considerable length of time, of constitutents which can be identified as derived from human excrements. So thoroughly can this conclusion be demonstrated that Dr. Beale states in his judgment "that the several constitutents of

* Jour. Roy. Micr. Soc., Sec. ser., vol. iv. (Feb. 1884), pp. 1–19.

human fæces are present in all the specimens of mud submitted for examination." Among the constituents of human food which Dr. Beale found, may be mentioned starch granules, fragments of vegetable tissue, the spiral fibers of cabbage, cooked muscular tissue and yellow elastic tissue, the latter in the state in which they are often found in fecal matter. Tea leaves, cotton fibers, probably from paper, fatty matter and crystals of fatty acids, fragments of paper and rags and many other substances were also present. "Even blood corpuscles of man or of one of the higher animals have been detected in the mud, having withstood all the destructive agencies to which they have been exposed, during probably many months."

Dr. Beale's paper furnishes methods of working and may be profitably consulted by anyone pursuing a similar line of investigation. The methods of bacterial investigation, which were just coming into use, were applied, with the result of showing the presence of immense numbers of bacteria in all the muds examined.

Following Dr. Beale's paper, there appeared in 1885, in the Report of the Royal Commission on Metropolitan Sewage Discharge, an extensive paper by Dr. H. C. Sorby; which is in many respects the most important contribution to the literature of sewage pollution that has yet appeared.*

In this paper Dr. Sorby covers substantially the ground traversed by Dr. Beale, with the addition of developing many points which Dr. Beale left untouched. He agrees with Dr. Beale as to the ease and certainty with which the microscope may be used to determine the presence of sewage in river muds.

The chief value of Dr. Sorby's paper lies in the development of a new method of quantitatively determining the amount of pollution in any given sample, and it is somewhat extraordinary that with a definite method of making such examinations before the scientific world for eight years it has not been more used. By its use the progress of the contaminating material may be traced down a stream, both in the flowing water and in the deposited muds; and consequently the quantity and quality of any self-purification which may be attained more thoroughly measured than by any other method of examination thus far made known.

Lortet's Results.

Probably the most useful study of this character in the way of definite results obtained is that of Lortet, as recorded in his paper The Pathogenic Bacteria of the Mud of the Lake of Geneva,† in which it is

* Report of a Microscopical Investigation of Thames Muds. By H. C. Sorby, LL.D., F.R.S. Appendix C. B. Report of Roy. Com. on Met. Sew. Dischg., p. 168.

† Centralblatt für Bakteriologie, ix., 709.

shown that sewage mud banks in lakes frequently contain living pathogenic forms of bacteria.

What the Several Studies Indicate.

The length of time which pathogenic bacteria may be expected to survive, when enveloped in masses of fecal matter, is, as noted in Chapter I., still somewhat uncertain, but what we positively do know teaches that there is nothing improbable in the assumption that sewage mud banks may easily become centers from which immense numbers of disease germs may be sent throughout the whole extent of the stream below the mud banks, at every time of flood flow. The fact that thorough sedimentation takes place in the course of a few miles' flow is therefore not only no guarantee of immunity at points below where the sedimentation occurs, but it may even be, independent of other circumstances, the source of the greatest danger in times of high water.

CHAPTER VI.

LEGAL ASPECTS OF THE CASE.

In the preceding chapters some of the physical features of stream pollution have been presented; we will now consider stream pollution from the legal point of view, though it may be premised that possibly the present discussion, as prepared by an engineer, must be taken as the views of a member of that profession interested in sanitary questions, rather than as those of an authority in law. It may be properly stated, however, that this chapter has been submitted to a legal friend of some attainment in the law of waters, and it is chiefly by reason of his opinion that the views advanced are, on the whole, sound from the legal point of view, that the authors have been encouraged to include this chapter in the present work.

How the Right of Property in a Water-course is Derived.

The right of private property in a water-course is derived from the ownership of the soil over which the stream naturally passes. It carries with it the right to have a stream passing through private lands flow as it is wont by nature, without material diminution or alteration. Persons holding real property to which these rights in running streams pertain are called riparian proprietors, while those whose lands border upon tide waters are called littoral proprietors. It is the rights of the riparian proprietor that it is proposed to briefly discuss here.

Riparian Proprietor's Right to a Stream in its Natural Condition.

According to the legal authorities, each proprietor has the common-law right that the stream shall flow to his land in the usual quantity and in its natural condition. No one proprietor has any property in the flowing stream which is not equally the right and privilege of every other, and each may apply it to any use to which it can be applied without material injury to the right of the other proprietors.

On this point the courts have held:

Every owner of land through which a stream of water flows is entitled to the use and enjoyment of the water, and to have the same flow in its natural and accustomed course, without obstruction, diversion, or corruption. The right

extends to the quality as well as the quantity of the water. If, therefore, an adjoining proprietor corrupts the water, an action upon the case lies for the injury.*

The right to the natural flow of water is not an easement but a natural right, which is not lost until an adverse easement has been acquired.†

We consider it as settled law that the right to have a stream running in its natural course, is not by a presumed grant from long acquiescence on the part of the riparian proprietors above and below, but is a *jure naturæ* . . . and an incident of property, as much as to have the soil itself in its natural state, unaltered by the acts of a neighboring proprietor, who cannot dig so as to deprive it of the support of his land.‡

In the case of the Commonwealth of Pennsylvania *v.* Soulas and others, decided in 1884, the common-law principles applying to stream pollution have been affirmed by the presiding judge in his charge to the jury with such clearness as to justify its reproduction in full here. The judge said:

The case which you are engaged in trying is one of much importance, and your responsibility is proportioned, of course, to its importance. The facts which have been proved by the evidence given on behalf of the Commonwealth are very few and simple. They are, however, very weighty, and it is my duty to add, have not been contradicted. The law also upon this subject is very plain. The defendants are charged in this indictment with maintaining a common nuisance by causing the excrement and foul water from the water-closets and urinals upon their premises, which are situated upon the bank of the Schuylkill river just above the confluence of the Wissahickon with that stream, to be drained into the river. It has been shown by witnesses, some of whom are experts in such matters, that the effect of this has been to pollute the drinking water of this city, and to render it unwholesome and dangerous. Such pollution has also been shown by competent and creditable evidence to have a direct tendency to produce disease in those who drink the water which is supplied to the city from the river Schuylkill.

Now, it is a very old and well-settled law that to pollute a public stream is to maintain a common nuisance. It is not only a public injury, but it is crime, a crime for which those who perpetrate it are answerable in a tribunal of criminal jurisdiction. An act of Assembly forbids and punishes as crimes all common or public nuisances, and I know of no public nuisance more serious in its evil effects and more obnoxious to the denunciation of the law than to corrupt and poison a public stream from which large numbers of people obtain their drinking water. If the jury, therefore, find that the defendants have done the acts charged against them in this indictment, no doubt whatever remains that they are guilty of the offence of maintaining a common nuisance, and ought to be convicted. If the water drained from the defendant's establishment into the river is of a foul and impure character, and if the effect of that is to pollute the water and render it unwholesome for drinking purposes, then they are guilty as they stand indicted, and it is your duty to say so.

It is no defence to say that the premises are in the same condition, and the drainage conducted in the same manner, as when they obtained possession and began their occupancy. Their continuance of the nuisance is itself an offence against the law for which they are personally responsible. The law is perfectly well settled that no man can prescribe for a public nuisance, or defend himself by showing that others have violated the law before him. No length of time can justify a public nuisance, although it may furnish an answer to an action for a private injury. Public rights are not destroyed by private encroachments, no matter how long they have endured. Nor is it any defence that the river is also polluted from other sources, that impurities flow into it from sewers, and from towns and places above

* Holsman *v.* Boiling Spring Bleaching Co., 14 N. J. Eq., 355.

† Stokee *v.* Singers, 8 Eh. & Bl. 36, Erle, J.

‡ Wadsworth *v.* Tillotson, 15 Conn. 366, 373.

Manayunk. If the defendants have contributed to the pollution, they are guilty. No man can excuse himself for violating the law upon the ground that others also violated it. It is said that the city ought to have built an intercepting sewer. But what of that? Perhaps it ought. But if the city has been guilty of negligence in that respect that fact does not justify the defendants in their violation of the law. It makes no difference whatever in the guilt of the defendants that the city has not taken steps to protect itself against the unlawful acts of those who pollute the stream. Nor ought your verdict to be affected in the slightest degree by the suggestion that if these pollutions of the river are stopped by indictments and convictions, the effect of that may be injurious to large business interests, which are prosecuted under similar conditions upon the river. You have nothing to do with that. Such considerations cannot affect your duty in the present case. The law is to be enforced, and those who violate it are to be punished, no matter what the effect of that may be upon their business, for the law is above every personal and private interest. All persons engaged in business are bound to conduct that business in subordination to the law, and in such manner as not to injure the public. It has been argued also that the city ought to have resorted to a civil remedy against the defendant for the correction of these abuses, that it ought to have gone into a civil court and asked for an injunction against their continuance. Such suggestions have nothing to do with the case. It is sufficient that the defendants are arraigned by the Commonwealth to answer for an infraction of her laws. If they have broken those laws, they are in the proper tribunal to answer for their acts. Civil proceedings are slow, and in such proceedings, where the parties are private persons or corporations, which are a kind of artificial persons created by the State, many embarrassing and dilatory questions might obstruct and hinder the speedy abatement of the nuisance. In my judgment the remedy which has been chosen is the speediest and the most effective. It is a proper, a lawful remedy, and you have no concern now with any other. The defendants are before you to answer the charge of maintaining a common nuisance, which is a public offence by the laws of Pennsylvania. The simple question which you have to decide is, whether the defendants are guilty of this offence. If they have done the acts which are charged against them in this indictment, then, as a matter of law, I instruct you that those acts constitute the offence of maintaining a common nuisance, and they are guilty. Upon the question of fact you have the testimony of numerous witnesses examined by the Commonwealth, and they have not been contradicted by any witness produced by the defendants.

While the foregoing citations have thus affirmed the right of every riparian proprietor to have the stream flow in its natural state, it is still true that the reasonable use of a stream by each proprietor may modify this right in some way, and it accordingly becomes an important question to determine when one riparian owner's use ceases to be rightful by infringing on the rights of others. In the English case of Embrey *v.* Owen, it was held that the right of a riparian owner to the flow of the stream in its natural state, without diminution or alteration, is not an absolute and exclusive right to all the water in its natural state, but is a right only to the flow of the water and the enjoyment of it, subject to the similar rights of all the proprietors.

From these citations it appears that the common law distinctly recognizes within certain limitations the natural right of every riparian proprietor to receive the natural flow of a stream essentially pure and undefiled. But by reason of the operation of the law of custom, certain modifications of this general principle have grown up which we may discuss a little in detail.

Natural and Artificial Uses of a Stream.

Before entering upon such discussion it may be noted that the law further recognizes ordinary, or natural, and extraordinary, or artificial uses of streams; the ordinary use being for the supplying of natural wants, as for instance, the use of water for such domestic purposes as drinking, bathing, cooking, and laundry, and for watering stock.

For these strictly natural uses the weight of authority is to the effect that any one riparian owner may, if necessary, consume all the water of the stream, though the exercise of such right is strictly confined to riparian land. Moreover, a stream, all the water of which is consumed by these ordinary natural uses of any one proprietor will usually be a very small one, though this fact cannot be considered as in any way affecting the application of the legal principle involved. But the fact that a city is itself a riparian proprietor does not authorize it to erect water-works and convey its supply several miles away. It can only take, without compensating the other owners, such an amount as will supply one family.* But the right of the one family to an undefiled water supply may nevertheless enable a municipality to insist on purity of the supply for the whole population under the common-law rule.

Actionable Pollutions.

According to Gould, who is the most recent American writer and who makes elaborate citations in relation thereto, the following distinct sources of pollution have been held to be actionable: The setting up of cattle-yards, hog-pens, or lime-pits for calf and sheep skins so near the water as to pollute it; discharging blood from a slaughter-house into the stream; erecting a cesspool, placing manure or oil, or permitting gas to escape, so near a well, spring, or stream as to pollute it; the casting upon one's own land of dirt and foul water or substances which reach the stream by percolation; the letting off of water made noxious by precipitation of minerals, or by dye wastes, liquors, madder, indigo, potash, sulphuric or muriatic acid; discharging into a stream heated water injuriously, sewerage or anything rendering the water unfit for domestic, culinary, or mining purposes, for cattle to drink, fish to live in, or for use in manufacturing.

A large number of cases are cited of actions brought for these various sources of pollution, and undoubtedly a more extended list could be easily made.†

* Swindon Water-Works *v.* Wilts and Berks Canal, L. R. 7 H. L. 697.

† Gould On the Law of Waters, 2d ed., 1891, sec. 219, pp. 431–432.

Distinction between Natural and Artificial Use.

The extraordinary or artificial use of a stream is such reasonable use, aside from the ordinary natural uses, as is common to all the proprietors. It differs from the ordinary use in this, that no one may for an extraordinary use appropriate the whole stream, but each proprietor has, as already stated, a right to the use of the stream subject to a like similar use on the part of all the others. Moreover, the right to the extraordinary use is inferior to the ordinary, and cannot be made to interfere with an ordinary use when such is clearly indicated as necessary to any of the proprietors. So long as the reasonable use of the common property does no injury to the rights of others who are entitled to a like reasonable use no action lies ; but an unreasonable use is an actionable injury.

The Case of Evans *v.* Merriweather.

A clear distinction of the difference between these two kinds of use was made for the first time in this country by the Supreme Court of Illinois, where the Court said :*

Each riparian proprietor is bound to make such a use of running water as to do as little injury to those below him as is consistent with a valuable benefit to himself. The use must be a reasonable one. Now the question fairly arises, is that a reasonable use of running water by the upper proprietor, by which the fluid is entirely consumed ? To answer this question satisfactorily, it is proper to consider the wants in regard to the element of water. These wants are either natural or artificial. Natural are such as are absolutely necessary to be supplied in order to his existence. Artificial, such only as by supplying them his comfort and prosperity are increased. To quench thirst, and for household purposes, water is absolutely indispensable. In civilized life, water for cattle is also necessary. These wants must be supplied, or both man and beast will perish. The supply of a man's artificial wants is not essential to his existence ; it is not indispensable ; he could live if water was not employed in irrigating lands, or in propelling his machinery. In countries differently situated from ours, with a hot and arid climate, water doubtless is indispensable to the cultivation of the soil, and in them, water for irrigation would be a natural want. Here it might increase the products of the soil, but it is by no means essential, and cannot, therefore, be considered a natural want of man. So of manufactures, they promote the prosperity and comfort of mankind, but cannot be considered absolutely necessary to his existence.

From these premises, the Court then proceeds to state the conclusion resulting, namely :

That an individual owning a spring on his land from which water flows in a current through his neighbor's land, would have the right to use the whole of it, if necessary to satisfy his natural wants. He may consume all the water for his domestic purposes, including water for his stock. If he desires to use it for irrigation or manufactures, and there be a lower proprietor to whom its use is essential to supply his natural wants, or for his stock, he must use the water so as to leave enough for such lower proprietor. Where the stream is small, and does not supply water

* Evans *v.* Merriweather, 3 Scan. (Ill.), 496.

more than sufficient to answer the natural wants of the different proprietors living on it, none of the proprietors can use the water for either irrigation or manufactures. So far then, as natural wants are concerned, there is no difficulty in furnishing a rule by which riparian proprietors may use flowing water to supply such natural wants. Each proprietor in his turn may, if necessary, consume all the water for these purposes. But where the water is not wanted to supply natural wants, and there is not sufficient for each proprietor living on the stream to carry on his manufacturing purposes, how shall the water be divided? We have seen, that, without a contract or grant, neither has a right to use all the water; all have a right to participate in its benefits. Where all have a right to participate in a common benefit, and none can have an exclusive enjoyment, no rule, from the very nature of the case, can be laid down, as to how much each may use without infringing upon the rights of others. In such cases, the question must be left to the judgment of the jury, whether the party complained of has used, under all the circumstances, more than his just proportion.

Riparian Proprietors Can Abrogate the Right to the Natural Use.

Concluding this part of the subject, it may be pointed out that the riparian proprietors can voluntarily, as by agreement, abrogate the right to the ordinary use of a stream, giving it up to such extraordinary uses as the exigencies of manufacturing or other artificial interests may be expected to subject it to. Custom for a series of years may be considered evidence of such voluntary abrogation.

Right to Use of a Stream Can be Acquired by Grant.

It is evident without special discussion, that the right to uses of a stream outside of the ordinary and reasonable extraordinary use may be acquired by grant or reservation the same as to real property. Such special rights are of the nature of easements, and can, like easements in real property, only be created by deed, devise, or record.

Prescriptive Rights in Streams.

There is, however, another way in which the right to the super-extraordinary use of a stream may be apparently acquired, namely, by prescription, and as this is the more important part of the subject for present purposes, we will discuss the matter a little at length.

By the common law the right to do a thing, which from the 1 ature of the case could have been created by a grant, may be acquired by an individual, by reason of long-continued and peaceable possession, and such right or title is denominated prescriptive, though the length of time required before such right can be held as acquired varies in different States. In New York it has been fixed by the Statute of Limitations at 20 years, while in some other States the lapsing of 15 years suffices. In order to constitute a prescription in England, according to the old writers, the enjoyment must have existed "time out of

mind," but in modern times not only there but in this country definite periods are fixed by the Statute of Limitations.

In its original sense the term prescription applied to incorporeal hereditaments and not to corporeal titles to land, as to easements of rights of way across land. In this sense prescriptive rights were originally enjoyed by adverse user, and finally by analogy came to include title to land by adverse possession. A further extension of the doctrine again led to a presumption of some title in running streams not justified by the common-law rule, this latter being also a prescriptive title by adverse user.

Angell has affirmed the principle of a prescriptive right to pollute water-courses under certain circumstances in the following language :*

> That a title to any incorporeal hereditament may be supported by an uninterrupted enjoyment for the period limited by statute for the right of entry upon land, was first laid down as law in England by Mr. C. J. Wilmot in the year 1761 . . . as twenty years' possession of land is considered a bar to an ejectment, so the possession of an easement attached to it for the same period is by analogy deemed evidence of right in the party possessing it. Indeed, it would seem absurd to acknowledge a right to a greater interest, as having been created by an enjoyment for a given space of time and to deny it to a lesser.

The Case of Bealy *v.* Shaw.

The case of Bealy *v.* Shaw, as cited by Angell, has been a leading case in England on the subject of acquisition of an adverse right to the use of a natural water-course; and it was decided in conformity to the doctrine above laid down. Lord Ellenborough, C. J., said:

> The general rule of law, as applied to this subject, is that, independent of any particular enjoyment used to be had by another, every man has a right to have the advantage of a flow of water in his own land without diminution or alteration, but an adverse right may exist, founded on the occupation of another, and, although the stream may be diminished in quantity, or corrupted in quality, yet if the occupation of the party so taking it and using it have existed for so long a time as may raise the presumption of a grant, the other party, whose land is below, must take the stream subject to such adverse right.

Popular Views of Prescription.

In administrating sanitary regulations for the protection of the drainage areas whence public water supplies issue, one quickly finds disseminated among both laity and professionals the idea that such rights of pollution as were enjoyed by the inhabitants, without contest or objection on the part of any of the riparian owners before the taking of a given stream for a public water supply, have become perscriptive through adverse use, and that such rights cannot be debarred except by the payment of a valuable consideration. The growth of this view is undoubtedly largely due to the strong affirmation of the

* Angell, Law of Water Courses, 6th ed., p. 351.

doctrine of right to pollute by adverse possession as stated in the foregoing from Angell. It is believed, however, that, in the present understanding of things, such a view is bad law, contrary, indeed, to the first principles of the common law, and an attempt will be made to make good that proposition.

The Law of Custom.

The laws of England, whence ours have been derived by inheritance, are defined by Blackstone as of two kinds,* the unwritten or common law, and the written or statute law, and it is from the former that we mostly derive our views as to prescription and adverse possession. We must observe in this connection that the common law is founded entirely in custom † and the *sine qua non* for the observance of the common-law maxim is that the custom itself be good, and the goodness of the custom under the common-law ruling depends, according to Blackstone, (1) upon its having been used from a "time whereof the memory of man runneth not to the contrary;" if any one can show the beginning of it the custom is not good; (2) it must have been continued; (3) peaceable, and acquiesced in, and (4) reasonable. A custom may be good if no good legal reason can be assigned against it. (5) Customs ought to be certain, and, (6) when established, compulsory and (7) consistent with each other. Moreover, Blackstone expressly says, in regard to the legality of a custom, that if it is not good it ought not to be longer used.

The Proper Application of the Fundamental Principles.

In the application of these fundamentals to the question of sewerage and drainage it is urged that practically all such privileges are recent. The time when the custom began may be readily defined by many. Again it is unreasonable for one human being to turn excrement into streams from which others may take drinking water. The matter looked boldly in the face is so revolting as to need no argument establishing its unreasonableness. Likewise it is inconsistent for human beings, either individually or in the aggregate, to pollute that which for their own uses should remain unpolluted, and, finally, when we understand as we now do, the serious effects of such pollution, the custom of turning sewage into any stream, which either is, or may in the future, be the source of a public water supply, is shown to be so utterly bad as to be worthy only of immediate abatement even though the custom has been maintained from time immemorial.

* Blackstone's Commentaries, sec. iii., On the Laws of England.

† Customs are either particular or general. It is particular customs only that we are concerned with here.

Moreover, the question of the right of the riparian proprietors to continue in the enjoyment of a right of pollution of which they may have been possessed at the time of taking of any given body of water as the source of a public water supply, has been the subject of a decision in the case of the water supply of the city of Boston, which may be considered as marking an era in sanitary history in this country. The case referred to is that of Augustus P. Martin, Mayor of Boston, *v.* Luther E. Gleason, in regard to which the following preliminary statement is made as derived from the city of Boston's brief.*

The Case of Lake Cochituate.

In 1846 the Legislature, by an act entitled "An act for supplying the city of Boston with pure water," authorized the city of Boston "to take, hold, and convey to, into and through said city the water of Long pond, so called (now Lake Cochituate), in the towns of Natick, Wayland, and Framingham, and the waters which may flow into and from the same, and any other ponds and streams within the distance of four miles from said Long pond, and any water rights connected therewith." Acts of 1846, Ch. 167, § 1.

Pursuant to this authority, and in part execution thereof, the city, in August, 1846, took certain water and water rights, described as, "all the waters of Long pond, so called, and other brooks and streams, whether permanent or temporary, entering into the same, and of all the bays, coves, and inlets thereof, and of the outlet of the same, and all the water rights thereunto belonging, or in any wise appertaining."

August 19, 1846, the city filed in the office of the registry of deeds for the county of Middlesex, the foregoing description of the taking, and a statement of the purpose for which taken, as required by said act of the Legislature (see copy, page 4 of the report); and, as soon as the necessary works could be constructed, proceeded actually to use, and has ever since used, said waters for the supply of its inhabitants. Pegan brook is, and has always been, one of the streams entering into Long pond. (Report, page 1.)

The defendant is the proprietor of a hotel in Natick, and all the human excrement discharged from the water closets, and all the sewage of his hotel are discharged directly into said brook in sufficient quantity to contaminate its waters. (Report, page 1.)

The city of Boston, by petition of its Mayor (St. 1884, c. 154), prays for an injunction to restrain the defendant from polluting this water supply.

The following is the decision of the Supreme Judicial Court, C. Allen, J.

Disregarding punctuation, as may properly be done in construing a statute (Cushing *v.* Worrick, 9 Gray, 385), and looking at the purpose and contemplated scope of Stat. 1846, c. 167, the city of Boston was authorized by Section 1 of that statute to take the water of Long pond, and the waters which may flow into and from the same, and any other ponds and streams within the distance of four miles from said Long pond, and any water rights connected therewith, so far as may be necessary for the preservation and purity of the same, for the purpose of furnishing a supply of pure water for the said city of Boston. This declared purpose relates back, and illustrates the extent of the authority conferred. Water-rights may be taken so far as may be necessary for the preservation and purity of the water. The words "and any water rights connected therewith" are not limited to the immedi-

* From 9th An. Rept. of Boston W. Bd., for yr. end. Apr. 30, 1885, pp. 76-79.

ate antecedent, namely, the "other ponds and streams" there referred to, but they also include Long pond itself, and the waters which may flow into and from the same. It was designed to give a broad and comprehensive authority for the purpose of furnishing a supply of pure water for the city, and to confer the power to take everything included within the meaning of the antecedent words, so far as might be necessary for the preservation and purity of the water. Section 15, imposing a penalty for wantonly or maliciously diverting the water, or any part thereof, of any of the ponds, streams, or water-sources which shall be taken by the city, or corrupting the same, or rendering it impure, confirms this view. Under this authority, the city might lawfully take any water rights connected with the waters flowing into Long pond, including the prescriptive rights which the plaintiff contends that he then had to discharge sewage into Pegan brook. It appears that this brook is and always has been a feeder of Long pond; and that the whole of it is within four miles of the pond. A prescriptive right to foul the waters of a stream is included under the term "water rights." This, indeed, is asserted by the defendant in his answer. It is a right in respect to the water of the stream; and the statute conferred power to take all water rights which might interfere with the purity of the waters taken. It is contended for the defendant that, if it was necessary to preserve the brook or the purity of the water, power was granted to the city to take the land on each side of the brook, and thus cut off any use either of it or of its waters; and, indeed, that the water-rights could not be taken separately from the land. But it does not appear to us to be necessary, even if it was competent, for the city to take the land on the sides of the brook in order to extinguish any prescriptive right to foul the water of it.

Assuming that the defendant had such prescriptive right, it is further contended that the city did not take it; but that the taking of the waters of the brooks and streams entering into Long pond only appropriated the water as it flowed into the pond at the time of taking, and subject to all legal burdens and uses then existing. This, however, is too narrow a construction of the description of what was taken. The city, after reciting the whole of the first section of the statutes, took all the waters of Long pond, "and other brooks and streams, whether permanent or temporary, entering into the same," "and all the water rights thereunto belonging or in any wise appertaining, for the sole use and benefit of said city." This language does not exactly follow the language of the statute; but we cannot doubt that it is broad enough to include Pegan brook, and the taking of "all the water rights thereunto belonging or in any wise appertaining," includes any right then existing to foul its waters. It is urged, by way of illustration, that, if a mill existed on the brook, the right to use the mill was not taken. But it is not necessary to consider that question here. It does not appear that there was any mill on the brook. If there was, the use of the water for turning its wheels might not foul the water, and might therefore be consistent with the purposes and rights of the city. But the right to use the brook as a discharge for sewage in large quantities, as practised by the defendant, is inconsistent with such purpose. If, therefore, the defendant had any such prescriptive right to foul the water of Pegan brook, as he claimed, such right was taken and extinguished by the act of the city under the Statute of 1846; and by Section 6 of that act the city was liable to pay all damages sustained thereby. The defendant, if he sustained damage, might have applied by petition for the assessment thereof at any time within three years from such taking. This remedy was the exclusive one.

It was not seriously contended in the argument that the defendant has acquired a prescriptive right to foul the waters since the taking by the city in 1846. Such prescriptive right could not be acquired, because the fouling of the water, since the right to foul it ceased, would be a public nuisance. Morton *v.* Moore, 15 Gray, 576. Brookline *v.* Mackintosh, 133 Mass., 125, 226.

Finally, it was contended for the defendant that, by reason of constructions erected by the city at the mouth of the brook, since the taking in 1846, the waters of Pegan brook do not, in fact, contaminate the water of the pond; and that, therefore, the city is not injured. It appears, however, as a fact, that the water of the brook is contaminated by the acts of the defendent. The city has a right to be protected against the necessity of maintaining works for the preservation of the

purity of the water from such a cause. If the acts of the defendant in fouling the stream have made it necessary for the city to resort to extraordinary means for preserving the purity of the water of the pond, he cannot justify the continuance of such illegal fouling by showing that the city has thus far been able, by the maintenance of special works, to prevent the natural result of his acts.

The result is that the petition for an injunction is maintained.

Injunction to issue.

Chancellor Kent's Views.

Kent has justly observed in his Commentaries "that the nature and extent of the right acquired by prior occupancy of a running stream becomes frequently an important and vexatious question between different riparian proprietors," * and, without going into his views extensively in this connection, it is sufficient to say that the tendency of American law as indicated by the decisions, is on the whole in the direction of an abridgment of the right to pollute by reason of adverse possession, though Kent says that if such occupation of a stream as corrupted it in quality has existed for so long a time as to raise the presumption of a grant and which presumption is the foundation of a title by prescription, the other party whose land is below must take the stream subject to such adverse right.

Gould's Definition of Prescription.

Gould has defined the law of prescription in its application to watercourses in this country with great clearness; and his numerous citations of recent cases are evidence of the most painstaking thoroughness. According to him a prescriptive right in the waters of a stream can only be acquired under substantially the following terms and conditions:

(1) The enjoyment must have been uninterrupted, adverse, and under a claim of right, and with the knowledge of the owner.

(2) The user must have been inconsistent with, or contrary to the interests of the owner, and of such a nature that it is difficult or impossible to account for it except on the presumption of a grant.

(3) The adverse use must be attended by circumstances of such notoriety that the person against whom the right is exercised may have reasonable notice that the right is claimed against him.

(4) The enjoyment must be as of right, and not by license or merely permissive.

(5) The burden of proof rests with the person claiming, to show that the use was adverse, uninterrupted, and known to the owner of the land.

(6) Prescriptive rights are limited in extent by the previous enjoy-

* Kent : Commentaries on American Law, sec. 446.

ment and cannot be materially varied to the injury of others. This amounts to saying that one proprietor cannot acquire the right by prescription to pollute the stream to a greater extent than it was polluted at the commencement of the 20 years.

Gould, in common with the other legal writers, affirms that "the right to pollute a stream to a greater extent than is permissible of common right may be acquired by prescription." But the conditions as defined in the foregoing indicate that prescriptive rights to polluting are limited in this country. In any case a public nuisance cannot be prescribed for howsoever long the adverse enjoyment may have existed.

English Cases.

In England many cases have arisen where riparian proprietors, aggrieved by the pollution of streams, have applied for injunctions restraining the offenders from continuing the pollution. The frequent success of such attempts are stated as among the first causes which led to attempts to purify sewage and manufacturing wastes.*

The right to pollute streams has been, however, in some cases included by prescription in the easements of estates on the banks of streams in England. Mr. Slater cites the case of a calico printer who began experiments on the purification of the waste waters from his works. Shortly after, he received a formal letter from the ground landlord warning him that by so doing, he was emperilling one of the prescriptive rights of the estate, and consequently violating one of the covenants of his lease. A clear case in which a misapplication of the law has led, as Mr. Slater remarks, to making river pollution not only facultative but a clear duty.

The English courts, however, have frequently gone to extreme lengths in protecting the rights of parties against pollution. Thus in the case of Goldsmid *v.* Tunbridge Wells Commissioners,† the plaintiff was tenant for life of an estate in which was a pond used for watering cattle, and in winter for supplying ice for domestic use. The defendants were commissioners with full power to make sewers and drains, and turn sewage into any water-course. The sewage was discharged into a brook flowing through the town, and which ran into the plaintiff's pond. The town grew constantly, and thus what at first was, in the language of the Court, "an imperceptible injury," had so increased in the course of years that, at the time of bringing the action, the water in the plaintiff's pond had become unfit for either watering cattle or furnishing ice. It was held that the discharge of the sewage of the town into the brook was a nuisance and the commissioners were restrained from continuing it.

* J. W. Slater: Sewage Treatment, Purification, and Utilization, p. 186.

† Goldsmid *v.* Tunbridge Wells Commissioners, L. R. 1, Ch. 349.

Original Application of the Doctrine of Adverse Possession.

The arguments and cases cited in the preceding, while not in any sense exhaustive, will serve in a general way to indicate how the views in regard to the right of pollution by adverse possession are likely to be modified as such cases become of more importance throughout this country. In order to show somewhat more clearly the further origin of the doctrine of prescriptive rights in natural water-courses, the following skeleton of the subject may be deemed sufficient:

As already noted, the doctrine of adverse possession in its first inception must be considered as having applied to land only, and its application later to rights in natural water-courses is, as also noted, an extension of the doctrine by analogy. In the case of land mere possession does not suffice, there must be some show of title, and as strengthening the show of title the person claiming may be deemed to have possessed and occupied in the following cases: (1) When the land has been cultivated or improved; (2) where protected by a substantial enclosure; (3) where not improved it has been used for the supply of fuel or fencing material; and (4) where a known farm or defined lot has been partly improved, the portion of such known farm or lot that may have been left uncleared or unenclosed, according to the local custom, shall be deemed to have been occupied for the same length of time as the part improved or cultivated. None of these can in the nature of the case by any possibility apply to rights in a water-course, and therefore user alone must be deemed the all-sufficient reason for the acquirement of a prescriptive title in a water-course by adverse possession. But the doctrine of ownership by mere user, even though enjoyed long enough to justify, in the absence of any other proof, the presumption of a title, is, as we now understand the matter, in its application to streams a bad custom, and may be, so far as the right of pollution is concerned, safely abolished, by rulings of our courts in line with the recent additions to human knowledge in the realm of bacteriological science.

The Relation of Legal Principles to the Development of Science.

The development of this view through the additions to knowledge which have followed from the recent studies in the etiology of disease is a very striking illustration of how after all, everything in the material universe is relative. So long as mankind looked upon disease as an infliction of Providence there could be no general conception of the danger arising from the contamination of a public water supply. This is finely illustrated by the conditions which exist to-day in many parts of India. The natives believe that the causation of disease is

beyond their control and refuse to accept any explanation of an epidemic of cholera other than that it is a visitation from the gods. Holding this view, they see no objection to placing their privies where the contents drain into reservoirs from which water supplies are drawn.* Nor will they yet listen to the plain teachings of experience, the result being that in many localities where such conditions exist, cholera is never absent. The unsanitary conditions produced by the Indian water tanks receiving quantities of privy drainage and other objectionable organic matter is intensified by the climatic conditions. In many localities the entire water supply must be stored through many months of tropical drought, and the stored waters by reason of the development of large quantities of infusorial and cryptogamic growth become in the end disgustingly offensive.

The Mill Acts.

There are in most of the States a series of enactments known as Mill Acts, which, founded in an extension of the doctrine of eminent domain, have as their object the encouragement of the erection of mills. In order to understand thoroughly certain modifications of the common-law principle in reference to the pollution of streams, which are essentially peculiar to this country, we may briefly consider the fundamental application of the law of eminent domain to rights in natural water, together with the cognate extension of the question which naturally arises.

The Law of Eminent Domain.

Eminent domain is defined as the right which the government retains over the estates of individuals to appropriate them to public use; but the exercise of this right has nevertheless attached to it as a necessary attendant condition, the principle that due money compensation shall be made to every individual whose property is taken, by operation of the law of eminent domain, without his consent.

The authority for the exercise of this transcendent power can only emanate from the legislatures, State or National; and the extent and circumstances under which it may be exercised are among the most important questions which can arise. In England, as with us, there must be a public object of adequate importance in order to justify its use, but Parliament, as the supreme power in the kingdom, may in express terms define to what extent the right may be transferred, as to corporations, private or municipal, etc.; and may also by statutory enactments define, in a general way, the methods, terms, and condi-

*See Blyth's, A Manual of Public Health, Fig. 53, p. 596. Tank in a Calcutta Bustee with Huts and Privies on its Edge.

tions of compensation. The conservative spirit in England has, however, usually led to embodying adequate compensation clauses in acts authorizing the exercise of eminent domain, although the extraordinary powers conferred upon some of the English railways are without precedent here.

In the Constitution of the United States it is defined by the fifth article that "private property shall not be taken for public use without just compensation," and if any legislature should, by enactment, overstep this plain constitutional provision, the courts could step in and by decision nullify such act as not within the constitutional powers delegated by the people to the legislature. Thus the legislature has, within reasonable limits, the power of determining whether a particular use is public or private, although the final decision in a doubtful case may rest with the courts.

Chief Justice Bigelow on Eminent Domain.

The subject of definition of the line between public use and private use was treated in a case in Massachusetts by Chief-Justice Bigelow, in the following manner :*

In many cases there can be no difficulty in determining whether an appropriation of property is for a public or private use. If land is taken for a fort, a canal, or a highway, it would clearly fall within the first class; if it was transferred from one person to another, or to several persons, solely for their peculiar benefit and advantage, it would as clearly come within the second class. But there are intermediate cases, where public and private interests are blended together, in which it becomes more difficult to decide within which of the two classes they may be properly said to fall. There is no fixed rule or standard by which such cases can be tried and determined. Each must necessarily depend upon its own peculiar circumstances. Many enterprises of the highest public utility are productive of great and immediate benefits to individuals. A railroad or canal may largely enhance the value of private property situated at or near its termini, but it is not for that reason any less a public work, for the construction of which private property may well be taken. . . . It has never been deemed essential that the entire community, or any considerable portion of it, should directly enjoy or participate in an improvement or enterprise, in order to constitute a public use within the true meaning of the words of the constitutional limitation. Such an interpretation would greatly narrow and cripple the authority of the Legislature, so as to deprive it of the power of exerting a material and beneficial influence on the welfare and prosperity of the State.

In a broad and comprehensive view, such as has been heretofore taken of the construction of this clause of the Declaration of Rights, everything which tends to enlarge the resources, increase the industrial energies, and promote the productive power of any considerable number of the inhabitants of a section of the State, or which leads to the growth of towns and the creation of new sources for the employment of private capital and labor, indirectly contributes to the general welfare, and to the prosperity of the whole community. It is on this principle that many of the statutes of this commonwealth by which private property has been heretofore taken and appropriated to a supposed public use are founded. One of the earliest and most familiar instances of the exercise of such a power under the

* Boston and Roxbury Mill. Corp. *v.* Newman, 12 Pink., 476.

Constitution is to be found in the Mass. St. 1795, c. 74, Sec. 1, for the erection and regulation of mills. By this statute the owner of a mill had power, for the purpose of raising a head of water to operate his mill, to over flow the land of super-riparian proprietors, and thereby to take a permanent easement in the soil of another, to the entire destruction of its beneficial use to him, on paying a suitable compensation therefor. Under the right thus conferred, the more direct benefit was to the owner of the mill only ; private property was, in effect, taken and transferred from one individual for the benefit of another, and the only public use which was thereby subserved was the indirect benefit received by the community by the erection of mills for the convenience of the neighborhood, and the general advantage which accrued to trade and agriculture by increasing the facilities for traffic and the consumption of the products of the soil. In like manner, and for similar purposes, acts of incorporation have been granted to individuals, with authority to create large mill-powers for manufacturing establishments, by taking private property, even to the extent of destroying other mills and water privileges on the same stream.

The Underlying Principle of the Mill Acts.

Having defined some of the more important features of the doctrine of eminent domain we may now proceed with the discussion of the Mill Acts, and their effect in practically modifying, in some of the States, the common-law rule in reference to the possible public nuisance caused by polluting running streams. The exercise of the prerogative of sovereignty in their enactment can only be justified on the ground of the public good, and their original inception in the early colonial period, when mills for grinding corn were an imperative necessity, is usually urged as their reason for being. Their effect in authorizing the overflow of another's land contrary to his wishes, on payment of a money consideration, has been to nullify to some extent by statute the natural right which every riparian proprietor has to the natural flow of a stream.

In Massachusetts, where manufacturing has always been a chief occupation of the people, the statutory law encouraging mills is ancient; and the several successive enactments in that State may be cited as showing on the whole the best development of this particular phase of the subject. The Massachusetts acts have been the basis of most of the similar laws passed in the Northern and Western States, while the original Virginia act, which differs very materially from the Massachusetts, has been the basis of similar acts in the several Southern States. In England in early times the construction of mills was encouraged in a different manner. Mills were erected by lords of manors on their respective domains for the public advantage, the gift being fettered by the condition that the people of the respective seigniories bring their corn to be ground at the mills so built ; this custom being called "doing suit" to the mill.* The American acts, however, as founded in the broader principle of the public good and

* Woolrych : On the Law of Waters and Sewers, 70, 108.

as extending the doctrine of eminent domain to the acquisition of rights in running water not authorized by the common law, are purely a development from the conditions of interdependence among the people which existed in the early colonial days. The progressive development in most of the manufacturing States has led practically to the enunciation of legal principles somewhat different from any of those derived by precedent from the laws of England. These new principles can hardly be considered as fully established in all parts of the country, although clearly in the line of the immemorial policy of a number of the States. Thus New York State may be cited as one in which no Mill Act has ever been enacted, and the Supreme Court, in the case of Hoy *v.* Cohoes Co.,* say " The Legislature of this State, it is believed, has never exercised the right of eminent domain in favor of mills of any kind. Sites for steam engines, hotels, churches, and other public conveniences, might as well be taken, by the exercise of this extraordinary power." The prevalence of this view of the matter in the State of New York has, however, operated to materially discourage such development of manufacturing interests as depend upon the construction of large storage reservoirs at points remote from the place where the stored waters are required for use, and in various other ways.

The Principle of Permissive Pollution.

The Mill Acts, while originally intended merely to secure to parties wishing to build mills the right to flow the lands of others, have nevertheless led, with other causes, to the development of what may be termed the principle of permissive pollution.

Again, it may be further said that their enactment, by tending to encourage manufactures, has led to a tacit modification by statute of the common-law rule in reference to moderate nuisances.

The Views of the Massachusetts Drainage Commission.

The Massachusetts Drainage Commission of 1884–5, discussed the various questions involved so broadly that we can hardly do better than to conclude this chapter by extended quotations from their report. The Commissioners say:

Manufacturing industry has from the earliest days been greatly favored by the law-makers of Massachusetts. To foster and encourage it they long ago substantially dedicated the unnavigable running waters of the land to its use. Believing its prosperity essential to the common welfare, the Legislature has not hesitated to step to the very verge of its constitutional power to stimulate and maintain it. For more than half a century persons have been authorized by law to dam up streams

* Hoy *v.* Cohoes Co., 3 Barb., 42.

and flood lands of others for their own private manufacturing ends. This taking of one man's property against his will for the individual benefit of another has been justified as a proper exercise of the prerogative of eminent domain, on the ground of the advantage inuring to the public from the improvement of water power, and the importance of encouraging manufactures. It has been supported also, upon the principle which permits the State to compel the several possessors of a common interest, which they cannot beneficially enjoy in severalty, to submit to measures esssential to secure a full and profitable use of their property.

As a general proposition of law it is laid down that the owners of the bed and banks of a stream have the right to use the running water in common from its source to its outlet. Each one has an equal right to its reasonable use as it flows by his land. This right of each is limited by the like right of every other. But this special qualified property of the individual in the water does not seem to exclude a general paramount interest which the public retains. Consequently, while no one can justly diminish his neighbor's enjoyment by greatly vitiating the water during his own short-lived tenure of it, neither may he destroy or greatly impair the public property in it. The factory or the mill may temporarily monopolize the flow, but they do so under an implied agreement not to spoil the water for the ordinary uses of the people in general. If they pollute the stream unduly they violate their license, and may be compelled to abate the nuisance they have made. Bnt while it is easy to lay down the principle, it is not easy to insist upon its rigid application without danger of working injustice and of frustrating the immemorial policy of the Commonwealth. An inflexible enforcement of a rule forbidding any defilement whatever might ruin many mill-owners and stop half the water-wheels of the State. Some diminution of purity is inevitable, and tolerable, while other contamination is unnecessary or excessive. The difficulty lies in distinguishing the legitimate from the destructive usage. A satisfactory definition is impracticable. Each case differs a little from the next. The circumstances may be utterly unlike. All will agree that some kinds of corruption may reasonably be sharply dealt with. No one, for example, pretends that he can rightfully pour human excrement and household filth into the water below his dam. Neither can he justify dumping into the river waste and refuse and garbage. On the other hand, the most exacting purist might not care to complain of the sediment washed from some bleachings or scourings, the slight taint of certain kinds of harmless chemicals, or the evanescent stain of dyes which are not unwholesome. The task is to discriminate the variety of shades of impurity which occur between these extremes.

Then there is a class of cases where it may be an open question whether it is not for the public interest to abandon a stream or sheet of water to the customary pollution of industry, so long as it does not imperil the public health. Unless this be admitted, the alternative may be to drive away thriving communities, and destroy the work of years of patient labor and active enterprise, undertaken under a presumed security of tenure. In such dilemma, if the water is not required for drinking purposes, a considerable contamination may be suffered without inordinate inconvenience. No doubt the State cannot entirely escape responsibility even by such a relinquishment as this. The public have a right not to be poisoned by the air they breath any more than by the water they drink. There is a foulness which is inadmissible even in a factory stream, which may embitter the life and undermine the health of the dweller upon its banks. In such cases the State is bound to intervene peremptorily if the riparian owners remain obstinately deaf to the public protest. Generally, however, before this stage is reached, the dirt of the earlier usage has so impaired the value of the water for some subsequent taker that he insists upon an abatement of the abuse above him.

We think it will be enough for the present to require that water for dwellings must be protected from every avoidable taint, while water for business must not be offensive or dangerous. All wanton ill usage, such as privies over the stream or cesspools draining into it, may well be put a stop to; and where the incidental injury characteristic of an industry is detrimental to the next user or to the public, it should be scrupulously restricted to absolutely unavoidable dimensions by the adoption of the most approved methods of remedial treatment.

But even if it should be thought expedient to impose some such restrictions as we

have indicated, there is still room for much difference of opinion as to the best method of enforcing whatever regulation is adopted.

There are several ways which naturally suggest themselves. We may leave the land owners, the water owners, and the community at large to the ordinary courts and to the common law to define and protect their various interests, or we may erect a special tribunal and prescribe by statute the scope and method of its oversight and jurisdiction, or the Legislature may pass upon each case as it arises. For reasons which we state in another place, we are inclined to recommend that the supervision of matters pertaining to water supply, sewerage, and the pollution of waters generally, be assigned to some board which shall be clothed with powers analogous to those of the Railroad Commissioners and Harbor Commissioners, to enable it to introduce system and method in these important departments of the common welfare.

We take it that no one will controvert the general proposition of law that every holder of property, however absolute and unqualified be his title, holds it under the implied liability that his use of it may be so regulated that it shall not be injurious to the rights of the community.

The Right of the Massachusetts Legislature to Prescribe Rules for the Protection of Streams.

In the exercise of its undoubted prerogative to watch over the general welfare and to guard the public rights by the ample police powers with which it is armed, the Legislature may make exactly such rules respecting the pollution of streams and ponds or other inland waters as it may judge requisite and necessary for the public welfare. It may absolutely prohibit, under suitable penalty, any contamination of any water within the borders of the Commonwealth, if it so please. It is a question always of expediency what degree of interference with individual liberty is required by the circumstances. Thus far the Legislature has been content to forbid any pollution of waters used directly or indirectly for a water supply by any city or town within twenty miles above the point of taking, provided this prohibition be not held to impair rights by statute before July 1, 1878, or prescriptive rights of drainage, to the extent to which they lawfully existed on that date. The Merrimack and Connecticut rivers and so much of the Concord as lies within the city of Lowell are also exempt from this rule. Nor can any person save those employed in getting ice or hauling lumber, drive a horse on any pond used as a water supply for domestic purposes by a city or town. Neither is bathing permitted in any such pond. The Legislature seems to have drawn the line at drinking water. Water dedicated to household uses is protected, within certain limits and to certain degree, by a speedy, peremptory, and effectual process. Municipal authorities may obtain an injunction at any time, from any justice of the supreme or superior court, to restrain any person from violating the 80th chapter of the General Statutes, which we have recited above. But all other waters are left to the ordinary rules of the common law. We think that a comprehensive knowledge of all the facts will satisfy any unbiassed inquirer that under this kind of customary guardianship of no one in particular, the general condition of our waters has suffered a steady degradation, or, to borrow the language of the State Board as long ago as 1876, "any defence against the impurities which so conveniently flow into our waters from the settlements and works on their banks has thus far been merely nominal; that is, the law can be used to prevent a nuisance from continuing to be poured into the river, but it is not used, because the process is too slow, cumbersome, and expensive." The lapse of nine years has only served to point and emphasize this commentary. The growth of population, the spread of modern refinements of living, the increase in industrial establishments, and all the indefinite multiplication of incidents appertaining to a prosperous and progressive community, must naturally and perhaps inevitably tend to vitiate the waters of its rivers and lakes. But even if a certain degree of taint be unavoidable, there is a vast amount which is wanton and preventable. A cursory glance at the report of Mr. Clarke will convince any one that there is no necessity whatever for a large part of the abuse to which our water-courses are subjected. It

is a question of time only, and that not a long time either, when, if we hold to the path we are travelling, we shall find ourselves face to face with a state of things as intolerable as that of England twenty-five years ago, when the Sewage of Towns Commission denounced it as an "evil of national urgency requiring the earliest and most serious attention." The condition of many of its important and frequented streams had become so filthy and disgusting that a universal protest arose, and large sums of money had to be expended in haste to mitigate the extremity of the offence. Meanwhile untold misery and mischief had been inflicted. Now, preventive measures are far less costly and much more effective than remedial expedients. We think it is high time that some steps should be taken here to arrest the progress of rivers pollution at the point it has reached in Massachusetts, and gradually to retrieve some portion, at least, of the ground we have carelessly yielded. Impressed with this conviction, we yet consider it impracticable to ask for a summary enforcement of the extreme right of the community in its waters now for the first time. Apart from technical points of law, and taking it upon broad, equitable grounds, it would be felt unfair for the community suddenly to insist upon a rigid exaction of its abstract right to clean waters after so many years of license and neglect. Even if it be law that no one can prescribe for a public nuisance, it does not necessarily follow that it is policy to abate all nuisances forthwith. And supposing such a project of law to have been enacted, we do not believe that the statute could or would be enforced. Certainly the existing law is not, then why should one so much more severe? We therefore cast about a good deal to hit upon some principle of classification, some scheme of discrimination, or even a mere frame of fixed regulations to guide the steps of a guardian of public waters. It was suggested that schedules might be made of streams which could be allowed a certain kind and amount of pollution, to be carefully defined, either in general or for each individual case. Certain others might be set apart and reserved for the standard purity expected for drinking water. While posssibly a few might be left to take care of themselves, at least for the present. It was held to be reasonable to forbid certain more dangerous or offensive trades from seating themselves in future at or near the fountain heads of rivers or brooks. It was urged that there would be no hardship in compelling a newcomer, whose labors must grievously deteriorate the quality of the water, to go below the industries which already depended upon the water as they were getting it, and could not endure without suffering any additional impairment of its purity.

These expedients, and many like them, were canvassed and weighed in turn, but to all there seemed to be grave objections. After much consideration it was decided to propound a plan of action which seemed to fit the exigency as well or better than any which occurred to us. It had, besides, the strong recommendation of shaping itself in exact conformity with precedents which have stood the test of time and have proved themselves to be valuable working agencies. In the year 1879 the Legislature intrusted the care of "the lands, flats, shores, and rights in tide-waters belonging to the Commonwealth," and the supervision of "all its tide-waters and all the flats and lands flowed thereby," to a Board whom it empowered "to prevent and remove unauthorized encroachments," or whatever "in any way injures their channels." Every work done within tidewater, not sanctioned by them or authorized by the General Court, where a license is required, is declared to be a nuisance, and the Board may order suits on behalf of the Commonwealth to prevent it or stop the removal of material from any bar or breakwater of any harbor. This legislation is strictly in line with that we offer. It is, indeed, almost identical with it. Alter its wording but a little and it would suit our purpose exactly. Precisely the same principle which enjoins a watchful care over the exterior waters of the State, would seem to call for at least an equal solicitude concerning the abuse of its interior waters. But mindful of the tenderness with which Massachusetts has always treated her industrial classes, we think it would be wise to embrace in the enactment one peculiarly characteristic feature borrowed from the act establishing a Railroad Commission, and which has proved strong enough to enforce amply all the rights of the public in that class of highways called railroads. This distinctive trait is the use of advisory as distinguished from mandatory power. We

think it would be well, then, for the Legislature to designate some one or more persons to look after the public interests in this direction. Let these guardians of inland waters be charged to acquaint themselves with the actual condition of all waters within the State as respects their pollution or purity, and to inform themselves particularly as to the relation which that condition bears to the health and well-being of any part of the people of the Commonwealth. Let them do away, as far as possible, with all remedial pollution and use every means in their power to prevent further vitiation. Let them make it their business to advise and assist cities or towns desiring a supply of water or a system of sewerage. They shall put themselves at the disposal of manufacturers and others using rivers, streams, or ponds, or in any way misusing them, to suggest the best means of minimizing the amount of dirt in their effluent, and to experiment upon methods of reducing or avoiding pollution. They shall warn the persistent violator of all reasonable regulation in the management of water, of the consequences of his acts. In a word, it shall be their especial function to guard the public interest and the public health in its relation with water, whether pure or undefiled, with the ultimate hope, which must never be abandoned, that sooner or later ways may be found to redeem and preserve all the waters of the State. We propose to clothe the Board with no other power than the power to examine, advise, and report, except in cases of violation of the statutes. Such cases, if persisted in after notice, are to be referred to the Attorney-General for action. Other than this, its decisions must look for their sanction to their own intrinsic sense and soundness. Its last protest against wilful and obstinate defilement will be to the General Court. To that tribunal it shall report all the facts, leaving to its supreme discretion the final disposition of such offenders. If such a Board be able to commend itself by its conduct to the approval of the great court of public opinion, it will have no difficulty, we think, in materially reducing the disorders and abuses which are threatening to give great trouble in future, if not speedily checked. If, however, we err in this expectation, and more drastic measures prove indispensable, the mandate of the State can always be invoked to re-enforce its advice.*

The Important Points.

The points which it is chiefly desired to enforce in this chapter are:

1. There is no natural right to pollute a water-course.

2. In the case of a stream which either is, or may be used, as the source of drinking water by any of the riparian proprietors, prescription, with the present understanding of the causation of the infectious communicable diseases, ought not be urged as the foundation of a right to pollute.

3. In case the interests of all the riparian proprietors are in favor of using a stream as a common receptacle for manufacturing wastes, mutual agreement, either actually expressed, or implied by the operation of custom, may dedicate the stream to such use, but such dedication cannot be construed to justify such unreasonable use as leads to the creation of a common nuisance.

4. The Mill Acts, while probably not in their original inception intended to cover the specific case of such pollution as renders the water

* For complete text of the Massachusetts Act which has been enacted as the result of the foregoing recommendations of the Drainage Commission, see Appendix IV.

of a stream unfit for domestic use, have still, by fostering manufacturing interests, created new customs and conditions, and consequently tend to modify the strict construction of the common-law rule.

5. From the Mill Acts, as a natural consequence of the development of manufacturing which they have fostered, has come a recognition of the principle of permissive pollution under State supervision as exemplified in the recent Massachusetts acts.

CHAPTER VII.

QUANTITY OF SEWAGE AND VARIATION IN RATE OF FLOW.

Before proceeding to the consideration of the various methods of sewage disposal, which experience has indicated as of value, we may properly inquire into the question of quantity and variation in the rate of flow of the sewage which it is proposed to treat.

Dearth of Accurate Information.

Accurate information as to quantity is rather difficult to obtain. But few observations have yet been made in this country, and aside from the few, the subject has been treated from a purely theoretical point of view. In England extensive observations were made by Mr. Haywood, Sir Joseph Bazalgette, and by the Referees in reporting upon the main drainage of London. Obviously the quantity of flow is closely related to the amount of the water supply, and inasmuch as the water supply of American towns is, as an average, at least double that of English, the experience gained by gagings there do not greatly assist in determining the quantity of sewage which may reasonably be expected in towns here. We may, therefore, consider in some detail the amount of water used in American towns, but it must be remembered that in designing sewage-disposal works general discussion can only be of use for indicating tested and approved methods of procedure. It cannot be too strongly insisted that each case stands by itself as a problem for special solution.

The Use of Water in American Cities.

Table No. 13 gives the average daily consumption of water per inhabitant for nearly 200 of the 348 cities in the United States, which, by the census of 1890, had a population of over 10,000. The wide variation in consumption shown by the table, it will be seen, is only in small part caused by the differences between the populations of the various cities. One of the chief causes for the variation in consumption is the variation in the proportion of the total population, which is quite clearly shown by the last column of Table 13, giving the population per tap for each city, so far as the figures are available. Other

TABLE No. 13.—AVERAGE CONSUMPTION OF WATER PER CAPITA IN CITIES OF THE UNITED STATES WITH A POPULATION OF OVER 10,000 IN 1890.*

Rank and name of city.	Population, 1890.†	Daily consumption.		Population per tap.‡
		Total.	Per inhabitant.	
1 New York, N. Y.	1,515,301	121,000,000	79	13.9
2 Chicago, Ill.[1]	1,099,850	152,372,288	140	....
3 Philadelphia, Pa.[2]	1,046,964	137,736,703	132	6.1
4 Brooklyn, N. Y.[3]	806,343	55,000,000	72	8.7
5 St. Louis, Mo.	451,770	32,479,000	72	14.8
6 Boston, Mass.[4]	448,477	42,173,100	80	6.6
7 Baltimore, Md	434,439	40,978,229	94	5.8
8 San Francisco, Cal	298,997	18,359,000	61	9.9
9 Cincinnati, O.[5]	296,908	33,997,007	112	8.5
10 Cleveland, O[6]	261,353	27,787,158	103	8.7
11 Buffalo, N. Y	255,664	47,517,137	186	6.3
12 New Orleans, La	242,039	8,976,715	37	54.0
13 Pittsburg, Pa,[7]	238,617	36,000,000	144	....
		11,509,000	153	8.2
14 Washington, D. C.[8]	230,392	36,588,629	158	6.5
15 Detroit, Mich	205,876	33,208,067	161	5.1
16 Milwaukee, Wis	204,468	22,380,783	110	11.1
17 Newark, N. J.[9]	181,830	14,079,793	76	8.6
18 Minneapolis, Minn	164,738	12,416,117	75	16 5
19 Jersey City, N. J.[10]	163,003	19,300,000	97	....
20 Louisville, Ky.	161,129	11,874,688	74	11.9
21 Omaha, Neb.[11]	140,452	14,000,000	94	24 0
22 Rochester, N. Y.	133,896	8,800,000	66	5.4
23 St. Paul, Minn	133,156	8,000,000	60	12.7
24 Kansas City, Mo.[12]	132,716	12,000,000	71	15.3
25 Providence, R. I.[13]	132,146	6,743,092	48	9.4
26 Denver, Col	106,713	20,000,000	187	7.0
27 Indianapolis, Ind	105,436	7,500,000	71	35.6
28 Allegheny, Pa	105,287	25,000,000	238	7 0
29 Columbus, O	88,150	6,882,333	78	11.5
30 Syracuse, N. Y.[14]	88,143	6,000,000	68	21 5
31 Worcester, Mass	84,655	4,971,340	59	8.9
32 Toledo, O	81,434	5,842,768	72	18.6
33 Richmond, Va	81,388	13,597,102	167	7.9
34 New Haven, Conn	81,298	11,000,000	135	...
35 Paterson, N. J	78,347	10,000,000	128	11.8
36 Lowell, Mass	77,696	5,127,199	66	9.2
37 Nasbville, Tenn	76,168	11,153,885	146	14.9
38 Fall River, Mass	74,398	2.136.182	29	14.9
39 Cambridge, Mass	70,028	4,489,180	64	6.6
40 Atlanta, Ga	65.533	2,359,564	36	20.0
41 Memphis, Tenn	64,495	8,000,000	124	11.9
42 Wilmington, Del	61,431	6,934,912	113	5.0
43 Dayton, O	61,220	2,848,926	47	20.1
44 Troy, N. Y	60,956	7,608,468	125	10.5
45 Reading, Pa	58,661	5,000,000	75	5.8

* Compiled from official returns included in the Manual of American Water-Works for 1890-91. Edited by M. N. Baker.

† Populations are according to the 1890 census, and for the whole city, regardless of the proportion of the population supplied.

‡ Tap or house service connection.

[1] Chicago. Figures are for main city works. Estimated populations supplied by small public plant built by former village of Washington Heights, and of former village of Pullman, supplied by a company. A total of 14,850 was deducted in finding averages.

[2] Philadelphia. Estimated populations of Holmesburg and Tacony, supplied by companies, 6.964.

[3] Brooklyn. Long Island Water Supply Co. supplies Twenty-sixth Ward, with population of 29,505.

[4] Boston. Supplies Somerville, with population of 40,152; Chelsea, 27,909; Everett, 11,068; total, 527,606.

[5] Cincinnati. Supplies Avondale and Clifton, with populations of 4,473 and 1,200, latter estimated; total, 302,581.

[6] Cleveland. Supplies Brooklyn and West Cleveland, with populations of 4,585 and 4,117; total, 270,055.

[7] Pittsburg. Monongahela Water Co. supplies "South Side," and outside towns with estimated aggregate population of 75,000.

[8] Washington. Figures are for July 1, 1891, and population is for the whole District of Columbia, the government of which and of Washington is now co-extensive.

[9] Newark. Supplies Belleville, through meter, population of which is 3,487; total, 185,317.

[10] Jersey City. Figures are for 1889. Supplies Bayonne, population of 19,033; Harrison, 8,338, and Kearney, 7,064; total, 197,483. *Report did not state* whether total average daily consumption includes supply to above places, but it is assumed that it did.

[11] Omaha. Supplies South Omaha; population, 8,026; total, 148,478.

[12] Kansas City. Supplies Kansas City, Kan., with population of 38,316; total, 171.032

[13] Providence. Supplies population in adjacent towns, estimated at 7,854; total, 140,000.

[14] Syracuse. Figures are for December, 1891, (approximate).

TABLE NO. 13.—Continued.

Rank and name of city.	Population, 1890.	Daily consumption.		Population per tap.
		Total.	Per inhabitant.	
46 Camden, N. J.	58,313	7,660,000	131	....
47 Trenton, N. J.	57,458	3,569,150	62	6.0
48 Lynn, Mass.	55,727	2,656,690	48	6.0
49 Lincoln, Neb.	55,154	2,500,000	45	38.0
50 Hartford, Conn.	53,230	1,772,129	33	8.0
51 St. Joseph, Mo.	52,324	2,500,000	48	27.0
52 Des Moines, Ia.	50,093	2,750,000	55	....
53 Portland, Or.	46,385	9,415,000	203	....
54 Lawrence, Mass.	44,654	2,770,592	62	49.0
55 Manchester, N. H.	44,126	1,932,073	44	32.0
56 Savannah, Ga.	43,189	5,851,610	135	....
57 Peoria, Ill.	41,024	4,000,000	97	....
58 New Bedford, Mass.	40,733	4,066,200	100	6.0
59 Erie, Pa.	40,634	4,546,919	112	6.0
60 Harrisburg, Pa.	39,385	5,856,937	150	4.0
61 Elizabeth, N. J.	37,764	2,500,000	66	10.0
62 Holyoke, Mass.	35,637	2,548,045	72	13.0
63 Binghamton, N. Y.	35,005	3,290,490	94	8.0
64 Wheeling, W. Va.	34,522	5,000,000	145	....
65 Augusta, Ga.	33,300	3,385,484	102	....
66 Youngstown, O.	33,220	1,634,687	49	20.0
67 Yonkers, N. Y.	32,033	2,176,396	68	11.0
68 Springfield, O.	31,895	1,704,069	53	16.0
69 Topeka, Kan.	31,007	1,600,000	52	20.0
70 Salem, Mass.	38,001	2,135,600	56	7.0
71 Altoona, Pa.	30,337	2,140,000	71	5.0
72 Terre Haute, Ind.	30,217	2,500,000	83	25.0
73 Elmira, N. Y.	29,718	2,250,000	76	15.0
74 Galveston, Tex.	29,084	905,753	31	7.0
75 Williamsport, Pa.	27,932	4,000,000	143	....
76 Bay City, Mich.	27,839	2,708,963	97	....
77 Houston, Tex.	27,557	3,750,000	97	23.0
78 Canton, O.	26,189	1,200,000	46	13.0
79 Birmingham, Ala.	26,178	4,250,000	162	9.0
80 Little Rock, Ark.	25,874	3,000,000	116	23.0
81 Taunton, Mass.	25,448	796,716	31	8.0
82 La Crosse, Wis.	25,090	2,162,196	86	17.0
83 Springfield, Ill.	24,996	2,571,223	103	14.0
84 Gloucester, Mass.	24,661	300,000	12	27.0
85 Newton, Mass.	24,379	985,396	40	5.0
86 Wichita, Kan.	23,853	2,400,000	101	20.0
87 Rockford, Ill.	23,584	2,373,100	101	9.0
88 Joliet, Ill.	23,264	1,747,134	75	....
89 Ft. Worth, Tex.	23,076	3,000,000	130	....
90 Oshkosh, Wis.	22,836	1,700,000	75	23.0
91 Muskegon, Mich.	22,702	1,385,188	61	20.0
92 Burlington, Ia.	22,565	1,592,509	71	13.0
93 Cohoes, N. Y.	22,509	3,000,000	133	15.0
94 Poughkeepsie, N. Y.	22,206	1,680,362	76	11.0
95 Montgomery, Ala.	21,883	800,000	37	17.0
96 Springfield, Mo.	21,850	1,217,000	56	15.0
97 South Bend, Ind.	21,809	1,873,653	86	15.0
98 Lewiston, Me.	21,701	2,462,231	114	10.0
99 Lexington, Ky.	21,567	800,000	37	27.0
100 Council Bluffs, Ia.	21,474	2,000,000	93	11.0
101 Racine, Wis.	21,014	484,360	23	11.0
102 Zanesville, O.	21,009	2,411,095	115	6.0
103 Woonsocket, R. I.	20,830	326,455	15	19.0
104 York, Pa.	20,793	1,250,000	60	5.0
105 McKeesport, Pa.	20,741	2,864,763	138	9.0
106 Chester, Pa.	20,226	3,000,000	148	4.0
107 Wilmington, N. C.	20,056	431,374	22	33.0
108 Bloomington, Ill.	20,048	799,730	40	18.0
109 Schenectady, N. Y.	19,902	2,246,967	113	14.0
110 Norristown, Pa.	19,791	2,250,000	114	....
111 Lynchburg, Va.	19,709	2,462,042	139	11.0
112 Newport, R. I.	19,467	1,500,000	77	6.0
113 Nashua, N. H.	19,311	2,067,819	107	6.0
114 Bangor, Me.	19,103	2,500,000	131	7.0
115 Waltham, Mass.	18,707	625,779	34	8.0
116 New Brunswick, N. J.	18,603	1,254,844	67	9.0
117 Sandusky, O.	18,471	2,475,823	134	9.0
118 Winona, Minn.	18,208	1,600,000	88	14.0
119 San Jose, Cal.	18,060	3,500,000	194	5.0
120 Kalamazoo, Mich.	17,853	1,896,600	107	14.0

TABLE NO. 13.—Continued.

Rank and name of city.	Population, 1890.	Daily consumption.		Population per tap.
		Total.	Per inhabitant.	
121 Norwalk, Conn	17,747	1,200,000	68	14.0
122 Hamilton, O	17,565	751,082	43	13.0
123 Jacksonville. Fla	17,201	991,194	58	16.0
124 Decatur, Ill	16,841	1,650,000	98	23.0
125 Sheboygan, Wis	16,359	450,000	27	22.0
126 Lafayette, Ind	16,243	1,500,000	92	13.0
127 San Diego, Cal	16,159	651,286	40	7.0
128 North Adams, Mass	16,074	1,500,000	93	16.0
129 Lima, O	15,987	609,371	38	12.0
130 Belleville, Ill	15,361	800,000	52	34.0
131 Rome, N. Y	14,991	2,063,648	138	12.0
132 Burlington, Vt	14,590	756,401	52	6.0
133 Austin, Tex	14,476	2,500,000	173	7.0
134 Keokuk, Ia	14,101	1,100,000	78	18.0
135 Atchison, Kan	13,963	600,000	43	17.0
136 Newburyport, Mass	13,947	400,000	29	9.0
137 Marlborough, Mass	13,805	347,885	25	8.0
138 New London, Conn	13,757	1,500,000	109	7.0
139 Rock Island, Ill	13,634	1,750,000	128	12.0
140 Port Huron, Mich	13,534	1,992,567	147	6.0
141 Woburn, Mass	13,499	775,963	58	6.0
142 Madison, Wis	13,426	535,480	25	11.0
143 Steubenville, O	13,394	1,500,000	112	4.0
144 Vicksburg, Miss	13,378	312,625	24	32.0
145 Battle Creek, Mich	13,197	410,000	31	14.0
146 Paducah, Ky	13,076	400,000	31	11.0
147 Passaic, N. J	13,028	400,000	31	19.0
148 Hannibal, Mo	12,857	1,130,000	82	11.0
149 Manistee, Mich	12,812	625,000	49	14.0
150 Dover, N. H	12,790	436,846	34	9.0
151 Raleigh, N. C	12,678	375,000	30	26.0
152 Portsmouth, O	12,364	1,500,000	121	9.0
153 Brookline, Mass	12,103	884,000	73	6.0
154 Moline, Ill	12,000	850,000	71	27.0
155 Bay City, Mich	12,981	2,708,963	209	8.0
156 Shreveport, La	11,979	1,159,115	97	22.0
157 Saratoga Springs, N. Y.[15]	11,975	3,000,000	251	5.0
158 Fort Scott, Kan	11,943	500,000	42	8.0
159 Hazleton, Pa	11,872	1,100,000	93	4 0
160 Pensacola, Fla	11,750	350,000	30	18.0
161 Cheyenne, Wy	11,690	1,500,000	128	14.0
162 Charlotte, N. C	11,557	500,000	43	....
163 Marinette. Wis	11,523	600,000	52	11.0
164 Nebraska City, Neb	11,494	200,000	17	22.0
165 Muscatine, Ia	11,454	400,000	35	29.0
166 Bridgeton, N. J	11,424	362,000	32	8.0
167 Streator, Ill	11,414	500,000	44	22.0
168 Chillicothe, O	11,288	750,000	66	12.0
169 Mahanoy City, Pa	11,286	400,000	36	8.0
170 Stillwater, Minn	11,260	1,000,000	89	19.0
171 Auburn, Me	11,250	500,000	44	10 0
172 Leadville, Col	11,212	1,000,000	89	11.0
173 Ithaca, N. Y	11,079	200,000	18	23.0
174 Denison, Tex	10,958	450,000	41	16.0
175 Ironton, O	10,939	1,700,000	155	9.0
176 Janesville, Wis	10,836	202,705	19	17.0
177 Fresno, Cal	10,818	2,500,000	23	5.0
178 Michigan City, Ind	10,776	1,000,000	93	30.0
179 Jacksonville, Ill	10,740	500,000	47	20.0
180 Butte City, Mon	10,723	850,000	79	....
181 Jeffersonville, Ind	10,666	150,000	14	31.0
182 Menominee, Mich	10,630	565,000	53	12.0
183 Meridian, Miss	10,624	800,000	75	17.0
184 Augusta, Me	10,527	1,000,000	95	....
185 Baton Rouge, La	10,478	200,000	19	58.0
186 El Paso, Tex	10,338	600,000	58	13.0
187 Cairo, Ill	10,324	800,000	77	15.0
188 Danville, Va	10,305	1,000,000	97	....
189 Alton, Ill	10,294	400,000	39	31.0
190 Asheville, N. C	10,235	350,000	34	20.0
191 Freeport, Ill	10,189	700,000	69	15.0
192 Sioux Falls, S. Dak	10,177	600,000	59	24.0
193 Peabody, Mass	10,158	826,940	81	6.0
194 Nanticoke, Pa	10,044	2,000,000	199	8.0
195 Jackson, Tenn	10,039	725,000	72	13.0

[15] The summer population is much greater than that given in the Table.

conditions affecting the consumption of water are the character of the population, whether requiring much water for other than domestic uses; the use of meters and other efforts to reduce waste; the source and mode of supply, whether from a source of unlimited capacity, through a proper supply and distributing system, or otherwise, and whether by gravity or pumping, the current expense for the latter sometimes tending to keep down consumption. Some of the figures for consumption are only approximate, but all were originally taken from official reports. The estimates are often indicated by their being an even number of millions or hundreds of thousands.

The Use of Water in Different Towns Does Not Follow Any Special Law.

The slight relation between the size of cities and their daily use of water per capita is more plainly shown in the summary, Table 13A, where the number of cities with consumption between certain limits is shown for cities of five different classes of sizes. While this summary shows a decrease in per capita consumption with the decrease in size

Table 13A.—Average Daily Consumption of Water (Gallons) Classified by Amounts and by Size of City.

Population.	200 or over.		100 to 199.		75 to 99.		50 to 74.		25 to 49.		Below 25.		Total.
	No.	P. c. total.	No.	P. c. total.	No.	P. c. total.	No.	P. c. total.	No.	P. c. total.	No.	P. c. total.	No.
Above 100,000	1	4	10	36	7	25	8	28	2	7	..	..	28
50,000 to 100,000	..	..	8	34	2	8	7	29	7	29	..	..	24
25,000 to 50,000	1	3	9	30	7	23	8	27	5	17	..	..	30
15,000 to 25,000	..	..	17	35	10	21	8	17	9	19	4	8	48
10,000 to 15,000	2	3	10	16	13	20	11	17	21	33	7	11	64
Totals	4	2	54	28	39	20	42	22	44	23	11	5	194

Population.	200 or over.		100 or over.		75 or over.		50 or over.		25 or over.		Total.
	No.	P. c. total.	No.	P. c. total.	No.	P. c. total.	No.	P. c. total.	No.	P. c. total.	No.
Above 100,000	1	4	11	40	18	65	26	93	28	100	28
50,000 to 100,000	..	..	8	34	10	42	17	71	24	100	24
25,000 to 50,000	1	3	10	33	17	56	25	83	30	100	30
15,000 to 25,000	..	..	17	35	27	56	35	73	44	92	48
10,000 to 15,000	2	3	12	19	25	39	36	56	57	89	64
Totals	4	2	58	30	97	50	139	72	183	95	194

of the city, there are so many exceptions that the rule can be accepted only in a very general way.

That there is a quite general increase in the population per water tap, with the diminution in the size of the city, is shown by Table 13 B, but the exceptions to this rule are numerous.

TABLE 13B.—POPULATION PER WATER TAP* CLASSIFIED BY NUMBERS AND SIZE OF CITY.

Population.	4 to 10.		11 to 20.		21 to 30.		31 to 40.		50 to 58.		Total.
	No.	P. c. total.	No.	P. c. total.	No.	P. c. total.	No.	P. c. total.	No.	P. c. total.	No.
Above 100,000	14	59	7	29	1	4	1	4	1	4	24
50.000 to 100,000	10	46	9	41	2	9	1	4	..	..	22
25,000 to 50,000	10	46	8	36	3	14	1	4	..	..	22
15,000 to 25,000	15	33	23	51	5	11	2	5	..	..	45
10,000 to 15,000	22	36	26	42	9	15	3	5	1	2	61
Totals	71	41	73	42	20	11	8	5	2	1	174

Population.	10 or less		20 or less.		30 or less.		50 or less.		Total.
	No.	P. c. total.	No.	P. c. total.	No.	P. c. total.	No.	P. c. total.	No.
Above 100,000	14	59	21	88	22	92	23	96	24
50,000 to 100,000	10	46	19	87	21	96	22	100	22
25,000 to 50,000	10	46	18	82	21	96	22	100	22
15,000 to 25,000	15	33	38	84	43	95	45	100	45
10,000 to 15,000	22	36	48	78	57	93	60	98	61
Totals	71	41	144	83	164	94	172	99	174

* In American water-works parlance, the word "taps" denotes the number of times the street water distribution main is "tapped" with service pipes to houses or other buildings.

The arrangement of cities by size, in Table 13, is intended to make more plain the variation in consumption per capita regardless of the size of the cities in question. This variation is still further illustrated, as is the effect of meters to reduce consumption, in Table 13 C, which gives the average daily consumption per capita of the fifty largest cities in the United States, arranged in the left half by consumptions greatest to least, the rank of the city in size and in consumption being given.

New York, the largest city in the United States, ranks twenty-third down the scale in water consumption per capita, while Allegheny, having the highest consumption, ranks twenty-eighth down the scale in size. There are a few cases of exact coincidence in rank of size and

TABLE 13 C.—CONSUMPTION OF WATER (GALLONS) AND USE OF METERS IN THE FIFTY LARGEST CITIES OF THE UNITED STATES.

Cities arranged in order of

Consumption, greatest to least.

Rank in: Size.	Rank in: Consumption.		Consumption per inhabitant.	Per cent. taps metered.	Population per tap.
28	1	Alleghany	238	0	7
11	2	Buffalo	186	0.2	6.3
34	3	Richmond	167	1.4	7 9
15	4	Detroit	161	2.1	5.1
14	5	Washington	158	0.3	6.5
13	6	Pittsburg (Co.)	153	small	8.2
38	7	Nashville	146	0.8	14.9
13	8	Pittsburg (Pub.)	144	0.2	....
2	9	Chicago	140	....	....
35	10	New Haven	135	....	....
3	11	Philadelphia	132	0.3	6.1
49	12	Camden	131	small	...
36	13	Paterson	128	small	11.8
46	14	Troy	125	3.9	10.5
43	15	Memphis	124	3.7	11.9
44	16	Wilmington	113	0.2	5
9	17	Cincinnati	112	4.1	8.5
16	18	Milwaukee	110	31.9	11.1
10	19	Cleveland	103	5.8	8.7
19	20	Jersey City	97	1.2	....
7	21	Baltimore	94	0.1	5.8
21	21	Omaha	94	19 4	24
6	22	Boston	80	5	6.6
1	23	New York	79	20.2	13.9
30	24	Columbus	78	6.4	11.5
17	25	Newark	76	2.4	8.6
48	26	Reading	75	0.1	5.8
18	26	Minneapolis	75	6.3	16.5
20	27	Louisville	74	5.9	11.9
33	28	Toledo	72	9.4	18.6
4	28	Brooklyn	72	2.5	8.7
5	28	St. Louis	72	8.2	11.8
27	29	Indianapolis	71	7.6	35.6
24	29	Kansas City	71	17.6	15.3
31	30	Syracuse	68	14.6	21.5
37	31	Lowell	66	22.9	9.2
22	31	Rochester	66	11.4	5.4
41	32	Cambridge	64	2.4	6.6
50	33	Trenton	62	small	6
8	34	San Francisco	61	41.4	9.9
23	35	St. Paul	60	4.2	12.7
32	36	Worcester	59	89.4	8.9
25	37	Providence	48	62.4	9.4
45	38	Dayton	47	3.8	20.1
12	39	New Orleans	37	0.4	54
42	40	Atlanta	36	89.6	20
40	41	Fall River	29	74.6	14.9
47	..	Grand Rapids (Co.)	..	15	....
47	..	Grand Rapids (Pub.)	..	12	...
39	..	Scranton (Two Co.'s)	..	....	...
29	..	Albany	..	0.4	6.2
26	..	Denver (Two Co.'s)	..	....	....

Taps metered, least to greatest.

Rank in: Size.	Rank in: Taps metered.		Per cent. taps metered.	Consumption per inhabitant.	Population per tap.
28	1	Allegheny	0	238	7
49	2 to 5	Camden	small	131	....
36		Paterson	small	128	11.8
50		Trenton	small	62	6
13		Pittsburg (Co.)	small	153	8.2
48	6	Reading	0.1	75	5.8
7	6	Baltimore	0.1	94	5.8
13	7	Pittsburg (Pub.)	0.2	144	....
11	7	Buffalo	0.2	186	6.3
44	7	Wilmington	0.2	113	5
3	8	Philadelphia	0.3	132	6.1
14	8	Washington	0.3	158	6.5
12	9	New Orleans	0.4	37	54
29	9	Albany	0.4	....	6.2
38	10	Nashville	0.8	146	14.9
26	11	*Denver	0.8	....	....
19	12	Jersey City	1.2	97	...
34	13	Richmond	1.4	167	7.9
15	14	Detroit	2.1	161	8.7
41	15	Cambridge	2.4	64	6.6
17	15	Newark	2.4	76	8.6
4	16	Brooklyn	2.5	72	8.7
43	17	Memphis	3.7	124	11.9
45	18	Dayton	3.8	47	20.1
46	19	Troy	3.9	125	11.5
9	20	Cincinnati	4.1	112	8.6
23	21	St. Paul	4.2	60	12.7
6	22	Boston	5	80	6.6
10	23	Cleveland	5.8	103	8.7
20	24	Louisville	5.9	74	11.9
18	25	Minneapolis	6.3	75	16.5
30	26	Columbus	6.4	78	11.5
27	27	Indianapolis	7.6	71	35.6
5	28	St. Louis	8.2	72	11.8
33	29	Toledo	9.4	72	18.6
22	30	Rochester	11.4	66	5.4
47	31	Grand Rapids (Pub.)	12	....	....
31	32	Syracuse	14.6	68	21.5
47	33	Grand Rapids (Co.)	15	....	....
24	34	Kansas City	17.6	71	15.3
21	35	Omaha	19.4	94	24
1	36	New York	20.2	79	13.9
37	37	Lowell	22.9	66	9.2
16	38	Milwaukee	31.9	110	11.1
8	39	San Francisco	41.4	61	9.9
25	40	Providence	62.4	48	9.4
40	41	Fall River	74.6	29	14.9
32	42	Worcester	89.4	59	8.9
42	43	Atlanta	89.6	36	20
35	..	New Haven	...	135	....
39	..	Scranton	....	....	....
2	..	Chicago	....	140	....

* Denver City Water Co.

consumption, but the two columns showing percentage of taps metered and population per tap, Table 13C, should always be examined in this connection.

The right-hand half of Table 13C, showing cities arranged in order of percentage of taps metered, least to greatest, illustrates the impor-

tance of the water meter as a factor in cities having sewage purification plants.*

The tendency of the per capita consumption of water to increase with the population is shown by Table 14, which gives the consumption for a few cities at scattering dates from 1860 to 1890.

TABLE NO. 14.—INCREASE IN DAILY CONSUMPTION OF WATER (GALLONS PER CAPITA) IN A NUMBER OF CITIES.†

Year.	Buffalo, N. Y.	Cincinnati, O.	Cleveland, O.	Detroit, Mich.‡	Jersey City, N. J.	Milwaukee, Wis.	Troy, N. Y.	Toronto, Ont.	Wilmington, Del.
1860........	....	30	14	52	77	....	....	....	....
1864........	....	...	22	57	....	....	....	....	....
1868........	....	....	25	67	....	....	....	....	....
1870........	58	40	33	64	84	....	....	....	....
1874........	60	55	45	87	86	....	....	....	....
1878........	....	66	51	113	....	....	....	55	59
1880........	105	75	65	125	....	106	58	65	80
1882........	106	76	68	149	124	....	....	71	94
1884........	130	....	82	144	....	106	134	95	96
1886........	132	74	91	178	137	113	133	96	92
1888........	153	107	...	210	....	....	....	....	....
1890........	186	112	103	161	97	110	125	100	113

† From a Report on Additional Water Supply, Rochester, N. Y. (1889), by A. Fteley and J. T. Fanning. Supplemented by figures from the Manual of American Water-Works for 1890–91.

‡ See Table 14A.

The increase in water consumption at Detroit from 1853 to 1892 is shown in detail by Table 14A, in which the consumption per family is the basis of comparison. The table also shows the effect of efforts to

TABLE NO. 14A.—WATER PUMPED PER FAMILY AT DETROIT, MICH., IN EACH OF THE 40 YEARS FROM 1853 TO 1892, INCLUSIVE.§

Years.	Families supplied.	Water pumped, gals. Total quantity.	Water pumped, gals. Per family.
1853............	4,283	303,531,743	70,868
1854............	4,619	376,265,126	84.450
1855............	5,282	542,807,364	102,765
1856............	5,706	692,124,305	121,297
1857............	6,189	697,190,523	112,659
1858............	6,474	718,091,207	110,919
1859............	6.794	782,112,587	115,118
1860............	6,750	870,036,451	125,185
1861............	7,128	895,129,423	125,579
1862............	7,275	994,945,329	136,762
1863............	7,699	1,035,798,043	134,534
1864............	7,993	1,019,390.256	127,410
1865............	8,351	1,040,514,887	125,675
1866............	9,089	1,196,317,922	131,622
1867............	10,242	1,425,535,230	139,184
1868............	11,544	1,666,545,125	144,364
1869............	12,774	1,946,810,325	152,400
1870............	13,722	1,866,060,068	136,000
1871............	14,896	2,300,150,605	154,414
1872............	16,035	2,782,292,578	173,513
1873............	17,019	3,198,393,948	187,930
1874............	18.853	3,289,872.635	174,511
1875............	19,606	4,207,454.260	214,660
1876............	20,102	4,065,134,470	202.225
1877............	20,345	4.213.239,790	207,090
1878............	20,603	4,345,743,330	210,927
1879............	21,341	5,129,599,110	240,348
1880............	22,465	5,552,965,310	247,183
1881............	23,749	6,543,127,968	279,722
1882............	25,442	6,284,000,742	243.062
1883............	27,415	7,379,327,788	260,170
1884............	29,424	8,510,614,440	289,260
1885............	30,533	9,970,829,580	326,886
1886............	31.946	10,576,571,254	331,070
1887............	34,486	13,168,859,808	381,869
1888............	36,863	14,380,166,670	390,098
1889‖..........	39,158	12,875,334,453	328,880
1890............	41,467	12,120.944,532	292,300
1891............	43,933	12,057,261,236	274,470
1892............	46,400	12,276,612,482	264,582

§ This table is taken from the report for 1892 of L. N. Case, Secretary of the Detroit Water Commissioners.

‖ Commenced metering.

* Table 13C was originally designed to show the effect of meters upon the consumption of water, and is taken from the Introduction to the Manual of American Water-Works, for 1890–91, p. xxvii. This table, with a somewhat extended discussion of the relation between the use of meters and water consumption, may be found in Eng. News, vol. xxvii., p. 63 (Jan. 16, 1892).

reduce a highly excessive waste of water by the use of meters, which were introduced in 1889, and not only at once lowered the total yearly water consumption, but also the consumption per family, so that the total yearly consumption, or pumpage, for 1892 was over two billion gallons, or some 14 per cent., less than in 1888.

Necessity for Considering Future Growth.

In designing sewage disposal works it will be necessary to take into account, the same as in designing the pipe system, the future growth of the town ; and by way of indicating what is now taking place in this particular in the United States Tables 15 and 16, derived from Census Bulletin No. 52,* are inserted.

Table No. 15.—Increase in Population in Ten Years in a Number of Cities and Towns of the United States with from 8,000 to 50,000 Inhabitants in 1890.

Names of cities and towns.	Population.		Increase.	
	1890.	1880.	Number.	Per cent.
Adams, Mass	9,213	5,591	3,622	64.78
Adrian, Mich	8,756	7,849	907	11.56
Akron, O	27,601	16,512	11,089	67.16
Alameda, Cal	11,165	5,708	5,457	95.60
Alexandria, Va	14,339	13,659	680	4.98
Allentown, Pa	25,228	18,063	7.165	39.67
Alpena, Mich	11,283	6,153	5,130	83.37
Alton, Ill	10,294	8,975	1,319	14.70
Altoona, Pa	30,337	19,710	10,627	53.92
Amesbury, Mass	9,798	3,355	6,443	192.04
Amsterdam, N. Y	17,336	9,466	7,870	83.14
Anderson, Ind	10,741	4,126	6,615	160.32
Ann Arbor, Mich	9,431	8,061	1,370	17.00
Anniston, Ala	9,998	942	9,056	961.36
Appleton, Wis	11,869	8,005	3,864	48.27
Arkansas City, Kan	8,347	1,012	7.335	724.80
Asbeville, N. C	10,235	2,616	7,619	291.25
Ashtabula, O	8,338	4,445	3,893	87.58
Athens, Ga	8,639	6,099	2,540	41.65
Atlantic City, N. J	13,055	5.477	7,578	138 36
Auburn, N. Y	25,858	21,924	3,934	17 94
Augusta, Ga	33,300	21,891	11.409	52.12
Bay City, Mich	27,839	20,693	7,146	34.53
Bayonne, N. J	19,033	9,372	9,661	103.08
Binghamton, N. Y	35,005	17,317	17,688	102.14
Bridgeport, Conn	48.866	27,643	21.223	76.78
Brockton, Mass	27,294	13,608	13,686	100.57
Brookline, Mass	12,103	8,057	4,046	50.22
Clinton, Ia	13.619	9,052	4,567	50.45
Cohoes, N. Y	22,509	19,416	3,093	15.93
Columbia, S. C	15,353	10.036	5,317	52.98
Columbus, Ga	17,303	10.123	7,180	70.93
Concord, N. H	17,004	13,843	3,161	22.83
Covington, Ky	37,371	29,720	7,651	25.74
Dallas, Tex	38,067	10.358	27.709	267.51
Dunkirk, N. Y	9,416	7,248	2,168	29.91
Framingham, Mass	9,239	6,235	3,004	48.18
Gardner, Mass	8.424	4,988	3,436	68.89
Green Bay, Wis	9,069	7,464	1,605	21.50
Harrisburg, Pa	39,385	30,762	8,623	28.03
Ithaca, N. Y	11,079	9,105	1,974	21.68
Jamestown, N. Y	16,038	9,357	6,681	71.40
Joliet, Ill	23,264	11.657	11,607	99.57
Kankakee, Ill	9,025	5.651	3,374	59.71
Lansing, Mich	13,102	8,319	4,783	57.49
Lawrence, Mass	44,654	39.151	5,503	14.06

* Urban Populations in 1890. April 17, 1891.

TABLE No. 16.—INCREASE IN POPULATION IN TEN YEARS IN CITIES OF THE UNITED STATES OF OVER 50,000 INHABITANTS IN 1890.

Name of city.	Population.		Increase.	
	1890.	1880.	Numbers.	Per cent.
Allegheny, Pa	105,287	78,682	26,605	33.81
Atlanta, Ga.	65,533	37,409	28,124	75.18
Baltimore, Md.	434,439	332,313	102.126	30.73
Boston, Mass	448,477	362,839	85,638	23.60
Brooklyn, N. Y	806,343	566.663	239,680	42.30
Buffalo, N. Y	255,664	155,134	100,530	64.80
Cambridge, Mass	70,028	52.669	17,359	32.96
Camden, N. J.	58,313	41,659	16,654	39.98
Charleston, S. C	54,955	49,984	4,971	9.95
Chicago, Ill.	1,099,850	503,185	596,665	118.58
Cincinnati, O.	296,908	255,139	41,769	16.37
Cleveland, O.	261,353	160,146	101.207	63.20
Columbus, O	88,150	51,647	36,503	70.68
Dayton, O.	61,220	38,678	22,542	58.28
Denver, Col	106,713	35,629	71,084	199.51
Des Moines, Ia.	50,093	22,408	27,685	123.55
Detroit, Mich.	205,876	116,340	89,536	76.96
Evansville, Ind.	50,756	29,280	21,476	73.35
Fall River, Mass	74,398	48,961	25,437	51.95
Grand Rapids, Mich	60,278	32.016	28,262	88.27
Hartford, Conn	53,230	42,015	11,215	26.69
Indianapolis, Ind	105,436	75,056	30,380	40.48
Jersey City, N. J	163,003	120,722	42.281	35.02
Kansas City, Mo.	132,716*	55,785	76,931	137.91
Lincoln, Neb	55,154	13,003	42,151	324.16
Los Angeles, Cal.	50,395	11,183	39,212	350.64
Louisville, Ky.	161,129	123,758	37,371	30.20
Lowell, Mass	77,696	59,475	18,221	30.64
Lynn, Mass	55,727	38,274	17,453	45 60
Memphis, Tenn	64,495	33,592	30,903	92 00
Milwaukee, Wis.	204,468	115,587	88,881	76.90
Minneapolis, Minn.	164,738	46,887	117,851	251.35
Newark, N. J	181,830	136,508	45,322	33.20
New Haven, Conn	81,298	62,882	18,416	29.29
New Orleans, La	242,039	216,090	25.949	12.01
New York, N. Y	1,515,301	1,206,299	309,002	25.62
Omaha, Neb.	140,452	30.518	109,934	360.23
Paterson, N. J.	78,347	51,031	27,316	53.53
Philadelphia, Pa.	1.046,964	847,170	199,794	23.58
Pittsburg, Pa	238,617	156,389	82,228	52.58
Providence, R. I.	132,146	104,857	27,289	26.02
Reading, Pa	58,661	43,278	15,383	35.54
Richmond, Va	81,388	63,600	17.788	27.97
Rochester, N. Y	133.896	89,366	44.530	49.83
St. Joseph, Mo	52,324	32,431	19.893	61.34
St. Louis, Mo.	451,770	350.518	101,252	28.89
St. Paul, Minn	133,156	41.473	91.683	221.07
San Francisco, Cal	298,997	233,959	65,038	27.80
Scranton, Pa	75,215	45,850	29.365	64 05
Syracuse, N. Y	88,143	51,792	36,351	70.19
Toledo, O.	81,434	50,137	31,297	62.42
Trenton, N. J.	57,458	29,910	27,548	92.10
Troy, N. Y	60,956	56,747	4,209	7.42
Washington, D. C.	230,392	177,624	52,768	29.71
Wilmington, Del.	61,431	42,478	18,953	44.62
Worcester, Mass	84,655	58,291	26,364	45.23

* Includes 13,048 population, which by recent decision of Missouri State Supreme Court, is now outside the limits of Kansas City.

Table No. 15, of cities and towns with populations ranging from 8,000 to 50,000 in 1890, includes only a portion of those given in the complete list in Census Bulletin No. 52. Only enough have been selected to indicate in a perspicuous manner the rapid increase of population in such towns at the present time. An analysis of the complete list in the Bulletin shows that of the total number of

nearly 400 such towns about 25 per cent. have more than doubled in population in the last decade. Moreover, the towns showing this large increase are situated in all parts of the country, many of them being in the older settled States, where it might be considered that fixed conditions are mostly attained. In the same way it is found that a considerable number of towns of the class indicated have increased in the period from 50 to 100 per cent.

If we examine the list of cities of over 50,000 population in 1890, we find that of the 56 which are listed in Table No. 16, only 14 per cent. exhibit an increase of more than 100 per cent., likewise the number increasing from 50 to 100 per cent. is proportionately smaller than in the class of towns illustrated in Table No. 15.

How to Determine the Law of Increase of Population.

Various attempts have been made to elucidate the law governing increase of population in towns, but thus far none of them can be considered wholly satisfactory. The problem presents itself with new features in nearly every town, and the decision of what the population may be at any future period becomes largely a matter of judgment, based upon the special conditions. To assist the judgment, the census returns for each ten-year period may be tabulated as in Tables No. 17 and 18 following :

Table No. 17.—Population of a Number of the Smaller Cities and Towns of the United States at Each Ten-Year Period from 1800 to 1890.

Name.	Population.									
	1800.	1810.	1820.	1830.	1840.	1850.	1860.	1870.	1880.	1890.
Alexandria, Va	4,971	7,227	8,218	8,241	8,459	8,734	12,652	13,570	13,659	14,339
Akron, O	......	......	......	......	......	3,266	3,477	10,006	16,512	27,600
Auburn, N. Y	......	......	......	......	......	9,548	10,986	17,225	21,924	25,858
Augusta, Ga	......	......	......	......	6,403	10,217	12,493	15,389	21,891	33,300
Bay City, Mich	......	......	......	......	......	......	1,583	7,064	20,693	27,839
Burlington, Vt	815	1,690	2,111	3,525	4,271	7,585	7,713	14,387	11,365	14,590
Binghamton, N. Y	......	......	......	......	......	......	8,325	12,692	17,317	35,005
Chelsea, Mass	......	......	......	......	2,390	6,701	13,395	18,547	21,782	27,909
Chester, Pa	957	1,056	657	817	1,790	1,667	4,631	9,485	14,997	20,226
Cohoes, N. Y	......	......	......	......	......	4,229	8,800	15,357	19,416	22,509
Dallas, Tex	......	......	......	......	......	......	......	......	10,358	38,067
Dover, N. H	2,062	2,228	2,871	5,449	6,458	8,196	8,502	9,294	11,687	12,790
Danbury, Conn	3,180	3,606	3,873	4,331	4,504	5,964	7,234	8,753	11,666	16,552
Fitchburg, Mass	1,390	1,566	1,736	2,169	2,604	5,120	7,805	11,260	12,429	22,037
Hamilton, O	......	......	......	......	......	3,210	7,223	11,081	12,122	17,565
Jacksonville, Fa	......	......	......	......	......	1,045	2,118	6,912	7,650	17,201
Lancaster, Pa	4,292	5,405	6,633	7,704	8,417	12,369	17,603	20,233	25,769	32,011
Malden, Mass	1,059	1,384	1,731	2,010	2,514	3,520	5,865	7,370	12,017	23,031
Manchester, N. H	......	......	761	877	3,235	13,932	20,107	23,536	32,630	44,126
Norristown, Pa	......	......	827	1,089	2,937	6,024	8,848	10,753	13,063	19,791
Newport, Ky	106	413	......	715	......	5,895	10,046	15,087	20,433	24,918
Steubenville, O	......	......	2,539	2,937	4,247	6,140	6,154	8,107	12,093	13,394
San Antonio, Tex	......	......	......	......	......	3,488	8,235	12,256	20,550	37,673
Wilkesbarre, Pa	835	1,225	755	2,232	1,718	2,723	4,253	10,174	23,339	37,718
Williamsport, Pa	131	344	624	......	1,353	1,615	5,664	16,030	18,934	27,132

TABLE No. 18.—POPULATION OF A NUMBER OF THE LARGEST CITIES OF THE UNITED STATES AT EACH TEN-YEAR PERIOD FROM 1800 TO 1890.

Name.	Population.									
	1800.	1810.	1820.	1830.	1840.	1850.	1860.	1870.	1880.	1890.
Baltimore, Md......	26,514	46,555	62,738	80,620	102,313	169,054	212,418	267,354	332,313	434.439
Boston, Mass.......	24.937	33,250	43.298	61,392	93,383	136,881	177,840	250,526	362,839	448,477
Brooklyn, N. Y.....	2,378	4,402	7,175	12,406	36,233	96,838	266,661	396,099	566.663	806,343
Buffalo, N. Y.......	......	......	......	8,668	18,213	42.261	81,129	117.714	155,134	255.664
Chicago, Ill.........	......	......	......	......	4,470	29,963	112,172	298,977	503,185	1.099,850
Cincinnati, O.......	......	2,540	9,642	24,831	46,338	115,435	161.044	216,239	255,139	296.908
Cleveland, O........	......	......	606	1.876	6,071	17,034	43,417	92.829	160,146	261,353
Detroit, Mich.......	......	......	1,422	2,222	9,102	21,019	45,619	79,577	116,340	205,876
New York, N. Y....	60,515	96,373	123,706	197,112	312,710	515,547	805.658	942,292	1,206,299	1,515,301
Philadelphia, Pa....	41,220	53,722	63,802	80,462	93,665	121.376	565,529	674,022	847,170	1,046,964
Rochester, N. Y....	......	......	......	9,207	20,191	36,403	48,204	62,386	89.363	133,896
St. Louis, Mo.......	......	......	10,049	14,125	16,469	77,860	160.773	310,864	350,518	457,770
Washington, D. C...	3,210	8.208	13,247	18,826	23,364	40,001	61,122	109,199	177,624	230,392
Worcester, Mass....	2,411	2,577	2,962	4,173	7,497	17,049	24,960	41,105	58,291	84,655

By plotting the series for any given town, the population curve is approximately determined. With the census record complete from 1800 to 1890, this curve may be usually projected from 10 to 20 years ahead with considerable probability of deducing results accurate enough to assist an engineer in determining what provision for future population may be reasonably made in designing works at any given place.*

Fig. 5, derived from the Preliminary Report of the Chicago Drainage Commission, illustrates the practical utility of such a method.

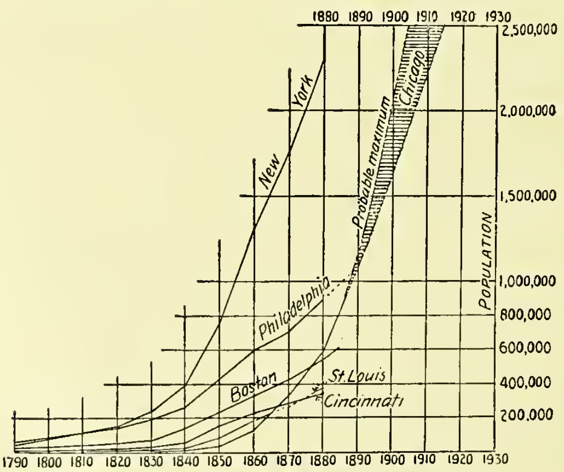


FIG. 5.—DIAGRAM ILLUSTRATING THE RATE OF GROWTH OF CITY POPULATIONS.

* For an excellent example of the analytical method of treating such a problem, see a Report on an Additional Water Supply for Boston, by Joseph P. Davis, city engineer, City Documents, No. 29, 1874. Mr. Davis there forecasts the population of Boston in 1890 as about 423,000; the census returns show it to be 448,477, while in 1870, the last return available at the time of making the computation, the population was 250,526.

Generalizations.

The tabulations here submitted, although hardly exhaustive, are sufficient to indicate how one may proceed in deducing the future population as the basis of rational design of permanent public works. As a rapid generalization, subject to exception in many cases, we may say:

(1) That in American towns under 50,000 population, the present rate of increase may be taken at about 100 per cent. in from 15 to 20 years.

(2) That in the larger towns the increase will be say 50 per cent. in the same time.

In connection with these generalizations, it is again strongly insisted that special studies in detail are required in each case.

Cause of Variations in Quantity of Sewage.

The foregoing Tables 13 to 13C showing the daily water consumption per capita, may be considered as affording an approximate indication of the probable dry-weather flow of sewage proper in the several towns, except that varying proportions of the population supplied with public water also enjoy sewer connections. Variations in quantity from the tabulated indications will be due chiefly, in addition to the above, to (1) infiltration of drainage water, and (2) to leakage from the sewers, both of which may be expected to frequently take place.

Of these two sources of variation infiltration will operate the most disastrously upon the success of disposal works, while leakage from the sewers, with its consequent pollution of the subsoil water, may injuriously affect the public health.

The Infiltration of Ground Water.

In reference to the amount of ground water likely to find its way into sewers definite information is rather scanty. In Boston, according to a discussion by Frederick P. Stearns, M. Am. Soc. C. E., chief engineer of the Massachusetts State Board of Health, the amount of ground water finding its way into the sewers of the main drainage system is about 45 gallons per inhabitant per day. The question of infiltration into the sewers of Boston and also into separate sewer systems from which storm water is excluded, is discussed at some length by Mr. Stearns, and it is sufficient for present illustration to merely point out the more important facts of the discussion.* It may be remembered, however, that many of the

* Special Report by Frederick P. Stearns, chief engineer, in Report of State Board of Health upon the Sewage of the Mystic and Charles River Valleys, pp. 90–96.

older sewers of Boston are of such open construction as to admit of relatively large infiltration of ground water. Some of them, moreover, follow the threads of old water-courses, which further leads to large contributions of ground water.

At East Orange, New Jersey, a separate system of sewers was carried out in 1886–88. In the latter part of November, 1893, there were about 33 miles of sewers in use, with 1,685 house connections. Many of the sewers are laid at such depths as to be over 20 feet below the level of the ground water. At a number of points quicksand was unexpectedly encountered, and the necessity for using about 4,000 feet of brick sewer on account of size required at the most unfavorable locations for making tight work, still further complicated the problem. The infiltration, as measured before any house connections were in use, was, for the vitrified-tile sewers (25 miles completed at the time of the measurement), 2.5 gallons per second; for the brick sewer, 5 gallons per second, the total infiltration amounting at these rates to 650,000 gallons per day. The flush-tank flow is estimated at 30,000 gallons per day, and the house-sewage flow from a contributing population of nearly 15,000 at 620,000 gallons per day. The infiltration is thus found to be 50 per cent. of the total quantity. Since the above measurements and estimates were made it is stated that the infiltration of ground water has been decreasing. Sewage disposal works are in use in connection with this system of sewers, and we will further consider the effect of this amount of ground water in describing the methods of disposal used at East Orange in Part II.*

Concluding this part of the subject, it may be noted that the results obtained under the extremely unfavorable conditions existing at East Orange of a leakage of only 2.5 gallons per second (216,000 gallons in 24 hours) from 25 miles of vitrified tile sewers, with 66,000 joints, is indicative that, under favorable conditions and with careful workmanship, a system of such sewers may be made nearly impervious, though in designing disposal works it will probably be safe to allow for an infiltration of perhaps 15 per cent. of the flow of sewage proper.

Provision for Rainfall in Combined System.

Where combined systems are in use it will be necessary in designing sewage disposal works, to provide furthei for a certain proportion of the rainfall, and just what proportion will be provided for must depend upon a number of considerations, as for instance:

(1) Whether the outfall sewers are, or can be arranged with refer-

* See paper on Inland Sewage Disposal, with Special Reference to the East Orange, N. J., Works, by Carroll Ph. Bassett, M. Am. Soc. C. E., in Trans. Am. Soc. C. E, vol. xxv., p. 125. Mr. Bassett was engineer of the works at East Orange.

ence to storm overflows, and if so arranged whether any portion of the storm water will go to the disposal works.

(2) If any proportion of the storm water is to go to the disposal works, then what proportion.

(3) The proportion of the total of any given rainfall which is likely to reach the sewers, the amount reaching them depending upon the slope of the area drained, and its relative imperviousness, as whether fully built up and paved.

It thus appears that when the rainfall is taken into account, the disposal problem is considerably complicated, and aside from the modifying circumstances pointed out in the chapter on The Infectious Diseases of Animals, the conclusion is reached that when some form of purification is to be provided, a separate system of sewerage appears preferable to the combined system by reason of not only the greater ease with which the more uniform flow of the separate system can be treated, but also by reason of the materially reduced expense of such treatment.

We will consider briefly the effect on the cost of sewage disposal works of actually providing for treating the whole of that portion of the rainfall which runs off into the sewers of a combined system as well as the sewage proper.

In the first place, it may be assumed that a considerable increase in capacity of disposal works would become inevitable in order to treat the rainfall, whatever the method of purification. Again, in order to prevent too great increase in capacity of disposal works, storage for the storm flow would naturally be provided with a view to extending the time of treatment of the excess flow of storms as much as possible. Without going into a discussion of the elements of the special problem of the proportionate amount of drainage which may be expected from the partially impervious areas of large northern towns, we will assume as sufficient for an illustration that 50 per cent. of a 24-hour rainfall may be expected to run off immediately; and that in towns with combined sewerage systems a treatment of the whole flow, including the rainfall, would require the provision of storage for nearly one-half of the greatest rainfall which can be expected in 24 hours. This large allowance will only provide for a summer rainfall, and a winter rain may occur when the whole area is impervious from the effect of frost; if such a rain occurs when the ground is further covered with snow we may have, because of melting of the snow, an amount of water flowing from a given area even greater than the total rainfall for the assumed unit of time of 24 hours. A provision of storage for 50 per cent. of the largest 24-hour rainfall must, therefore, be considered conservative for our northern climates. In the South, with moderate winters of little or no snow, we may take the percentage flowing off as somewhat

less, say at 40 per cent. Southern towns, too, are built with more open space than northern, from which it follows that the impervious area is relatively less in proportion to the whole area, whence we derive another reason for using a smaller per cent.

Assuming a town with an area of 5,000 acres and maximum 24-hour rainfall of 2 inches, the storage required would be 136,000,000 gallons.

If we apply these figures to larger areas we find that in the great cities the quantity of water derived from the rainfall is so great that

TABLE NO. 19.—HEAVIEST RAINFALLS IN 24 HOURS AT MILWAUKEE, WISCONSIN, 1871 TO 1892, INCLUSIVE.*

(From 8 P. M. to 8 P. M.)

Year.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1871	2.50	.78	.50	1.70	1.10	1.02	1.06	.91	.16	1.45	1.15	1.41	2.50
1872	.21	.12	.16	.42	.67	1.43	.90	.80	3.74	.22	1.05	.21	3.74
1873	1.49	.06	.38	.62	1.90	.74	.77	2.03	1.24	.72	.99	.58	2.03
1874	.84	.30	1.04	1.63	1.17	1.39	1.56	.57	1.27	1.52	1.06	.48	1.63
1875	.43	.45	.48	1.03	2.70	2.14	.86	.87	1.35	.83	.34	1.13	2.70
1876	1.90	1.07	.85	1.35	1.82	.84	2.10	2.71	.77	.54	1.80	.81	2.71
1877	1.13	.06	.88	2.92	.36	1.42	.98	1.63	.26	1.09	.93	1.04	2.92
1878	.83	1.76	.75	1.55	1.06	1.23	.94	.32	1.43	1.25	.36	.22	1.76
1879	.32	.69	.25	1.58	.80	.93	1.07	1.30	.84	1.05	.87	.59	1 58
1880	.87	.99	.72	1.26	1.19	1.56	.81	.65	.86	.17	.47	.20	1.56
1881	.71	1.01	1.79	.21	1.38	1.07	1.32	.49	.70	1.61	.44	.56	1.79
1882	.14	1.06	.61	.45	.71	1.36	.66	2.17	.63	.79	.45	.41	2.17
1883	.38	.91	.06	.26	.95	.49	1.17	.16	.89	.67	.75	.31	1.17
1884	.30	.32	.64	1.05	.34	2.03	1.44	.41	1.29	.43	.54	.72	2.03
1885	.71	.12	.09	1.02	.19	1.81	.85	2.09	1.74	.81	.88	.72	2.09
1886	.86	.43	.99	.86	.94	.99	.35	1.95	.68	1.25	.47	.37	1 95
1887	1.13	.84	1.00	.52	.75	.23	2.98	.82	1.14	.89	.32	.82	2.98
1888	.35	.15	.50	1.05	.53	.94	1.25	1.00	.38	.51	.36	1.13	1.25
1889	.37	.36	.32	.80	1.20	1.94	1.01	. 52	.32	.20	.68	.45	1.94
1890	1.00	.72	.64	1.05	1.25	1.07	1.07	.88	.30	.46	.77	.16	1.25
1891	1.23	.47	.88	2.00	1.14	2.53	1.44	1.01	.14	.93	1.37	.65	2.53
1892	1.38	.75	.74	.76	1.55	1.04	.61	2.52	1.20	.92	.49	.77	2.52
Period	2.50	1.76	1.79	2.92	2.70	2.14	2.98	2.71	3.74	1.52	1.80	1.41	3.74

* Amounts are expressed in inches.

TABLE NO. 20.—HEAVIEST RAINFALLS IN 24 HOURS AT DETROIT, MICHIGAN, 1871 TO 1892, INCLUSIVE.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1871	.85	1.25	1.05	.72	1.09	1.05	.21	.41	.60	.46	1.55	1.00	1.55
1872	.68	.31	.46	.42	2.06	1.27	.58	1.06	.81	.40	.22	.22	2.06
1873	1.61	.11	.40	1.72	.89	.55	1.00	.05	.96	.86	.36	1.58	1.72
1874	1.31	.56	.82	.63	1.00	1.87	.76	.89	.25	.43	.60	.25	1.87
1875	.22	.60	1.25	.56	2.12	1.39	1.44	1.88	1.31	1.05	.43	1.01	2.12
1876	.47	2.41	1.15	.69	1.65	.38	1.68	1.09	.46	.90	.86	.54	2.41
1877	.47	.02	1.13	1.22	.34	1.35	.87	2.02	.12	2.02	1.57	.30	2.02
1878	1.48	.60	.49	.97	.96	1.16	2.48	1.03	.98	1.03	1.19	1.35	2.48
1879	.37	.42	.35	.43	1.78	1.03	2.05	.60	3.21	.34	1.16	1.09	3.21
1880	.54	.25	1.35	1.57	1.61	1.66	1.68	1.20	2.08	1.20	1.64	.24	2.08
1881	.66	1.17	.93	.75	1.09	1.62	2.25	1 10	1.38	1.95	1.15	1.15	2.25
1882	.53	.66	.93	.45	1.68	.99	.53	1.06	.86	.82	.37	.42	1.68
1883	.43	1.12	.75	.61	1.20	.63	1.31	.26	.53	.51	.81	.55	1.31
1884	.35	.55	.41	.41	.54	.81	1.35	.86	.67	.91	.68	.63	1.35
1885	.58	.68	.24	.75	1.28	1.08	.84	1.16	.65	.33	.63	1.04	1.28
1886	.45	.24	.47	2.41	.76	.69	2.31	.54	.94	.34	.99	.60	2.41
1887	.31	1.24	.49	.58	1.02	1.51	.66	1.06	1.18	.50	1.46	.71	1.51
1888	.50	.70	.77	.71	.60	.70	1.27	4.42	.68	.67	1.46	.53	4.42
1889	.39	.24	.83	.46	2.57	1.24	.62	.10	.37	.61	.80	.88	2.57
1890	.95	.55	.47	.88	1.50	.99	.94	2.72	.67	1.29	1.51	.58	2.72
1891	.58	1.32	1.00	1.10	.52	.82	1.04	.83	.97	1.19	1.43	.54	1.43
1892	.42	.52	.78	.71	2.22	3.39	1.07	1.09	2.75	.16	1.15	.42	3.39
Period.	1.61	2.41	1.25	2.41	2.57	3.39	2.48	4.42	3.21	2.02	1.57	1,58	4,42

to hold it in storage and treat it becomes a practical impossibility. As a compromise, then, we could only hope to provide for treating the first flow of rain water, which, as containing the bulk of the street washings, may be looked upon as the most important. In this view we would provide for perhaps 5 to 10 per cent. of the maximum 24-hours rainfall.

In order to illustrate this phase of the question, several tables of maximum rainfalls in different parts of the country are included.

TABLE No. 21.—HEAVIEST RAINFALLS IN 24 HOURS AT CLEVELAND, OHIO, 1871 TO 1892, INCLUSIVE.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1871	.16	1.03	1.20	.24	.64	1.55	1.19	3.14	.27	.28	1.05	.55	3.14
1872	1.00	.27	.27	.59	.91	1.26	2.32	1.35	1.00	.67	.30	.52	2.32
1873	.48	.78	.66	1.23	1.00	2.11	.85	.75	.66	.88	.46	1.87	2.11
1874	1.54	1.33	.38	.36	.66	1.65	2.13	1.28	1.13	.34	.53	1.09	1.65
1875	.45	.26	.91	.61	1.06	1.26	.45	1.55	1.87	.80	1.00	.66	1.87
1876	1.27	1.66	.65	.43	2.10	1.28	.69	1.45	1.53	1.56	.59	.73	1.66
1877	.80	.07	1.32	1.04	.25	1.34	1.05	2.59	1.40	1.39	.91	.45	2.59
1878	1.85	.55	1.13	.70	.82	.44	2.46	1.34	2.30	1.23	.72	.70	2.46
1879	.71	.64	.59	.58	.54	.90	2.69	2.59	.66	.45	.74	.86	2.69
1880	.59	1.32	1.08	1.06	1.01	1.86	2.51	.87	.85	.66	1.36	.31	2.51
1881	.91	.72	.53	.42	.16	3.01	.41	.12	.97	2.45	1.41	1.22	3.01
1882	.74	.87	1.08	.70	1.04	1.89	2.06	.83	2.09	.60	.44	.91	2.09
1883	.49	3.62	.34	.65	1.40	.93	.74	1.78	.95	1.41	1.07	.44	3.62
1884	.39	1.22	.35	.71	1.34	2.28	2.02	.82	1.28	.50	.50	.30	2.02
1885	.44	.57	.24	.85	1.16	2.12	1.02	1.14	.72	.78	1.49	.67	2.12
1886	.89	.46	.43	.74	.36	.27	1.42	.53	1.43	.29	1.39	.91	1.43
1887	.30	1.46	.77	.73	.94	.58	.46	1.44	1.21	.70	.84	.57	1.46
1888	.84	.54	.86	.84	1.13	1.00	1.38	.87	.66	.81	.84	.26	1.38
1889	.81	.27	1.42	.60	1.88	.43	1.20	.40	.84	.70	.80	.54	1.88
1890	.70	1.28	1.02	.58	1.16	1.43	1.65	.90	1.95	.84	.97	.33	1.95
1891	.74	1.45	.75	.29	1.58	1.39	.47	1.21	1.37	.57	2.19	.75	2.19
1892	.73	.71	1.23	.79	1.70	1.17	1.28	1.41	.78	.27	.85	.33	1.70
Period	1.85	3.62	1.42	1.23	2.10	3.01	2.69	3.14	2.30	2.45	2.19	1.87	3.62

TABLE No. 22.—HEAVIEST RAINFALLS IN 24 HOURS AT ROCHESTER, NEW YORK, 1872 TO 1892, INCLUSIVE.

Year.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1872	.72	.38	.67	.50	.44	2.28	.79	.59	.55	1.74	.56	.70	2.28
1873	.50	.58	2.01	1.15	.86	.62	2.10	1.16	1.45	3.77	.76	.98	2.10
1874	1 37	.91	.53	1.31	1.02	1.16	1.75	.26	.90	.62	.53	.49	1.75
1875	.19	.43	.93	.55	.58	.69	.69	1.90	1.29	.78	.68	.59	1.90
1876	.84	1.46	.97	.42	.45	1.67	.90	.25	1.30	.21	.29	.31	1.67
1877	1.21	.22	.67	1.05	.70	.69	2.05	1.13	.73	.95	1.15	.92	2.05
1878	2.11	1.45	1.56	.85	.71	.65	1.14	1.14	.30	2.34	1.87	1.64	2.34
1879	1.71	.91	.57	.21	.62	1.29	1.27	2.65	.82	.25	1.46	.67	2.65
1880	.77	1.37	.38	.58	1.77	.46	.75	1.75	.88	1.90	.76	.46	1.90
1881	.90	.76	1.52	.60	1.30	.68	.79	.69	.83	.61	.67	.88	1.52
1882	.50	.49	.53	.51	1.06	.88	.44	1.07	.47	.39	.36	.30	1.07
1883	.13	.45	.68	.48	1.92	...	...	...	...	.55	.63	.48	...
1884	1.24	.33	1.09	.55	1.00	1.80	1.87	.92	.92	1.03	.44	.52	1.87
1885	.71	.52	.18	1.48	.55	1.67	1.29	.65	.84	.72	.51	.73	1.67
1886	.67	.81	.79	1.80	.76	1.56	.25	3.34	.83	.70	1.15	.58	3.34
1887	.27	1.57	.26	1.40	.68	.42	.73	.56	.29	.34	.27	.52	1.57
1888	.32	.30	.54	.32	.40	1.66	.54	1.20	.80	.68	.46	.59	1.66
1889	.96	.40	.58	1.18	1.92	1.49	.92	.63	.78	1.82	1.37	.48	1.92
1890	.76	.84	.67	.75	1.32	.74	.83	.48	2.10	1.07	2.26	.57	2.26
1891	1.18	1.30	1.25	.56	.47	1.04	1.42	.70	.39	1.52	.68	.90	1.52
1892	.74	.59	.68	.34	1.34	2.00	2.10	1.32	.38	.34	.90	.32	2.10
Period	2.11	1.57	2.01	1.80	1.92	2.28	2.10	3.34	2.10	3.77	2.26	1.64	3.34

TABLE No. 23.—HEAVIEST RAINFALLS IN 24 HOURS AT CINCINNATI, OHIO, 1871 TO 1892, INCLUSIVE.

Year.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1871	.60	2.00	1.40	.80	.50	no data	.90	2.00	1.05	.30	1.85	2.50	..
1872	.55	.55	.65	1.73	1.36	1.58	1.81	.88	.93	1.18	.85	.85	1.81
1873	.58	1.53	.55	.61	.95	.65	.92	1.39	1.12	.80	2.75	2.75	2.75
1874	1.20	2.73	1.47	1.06	.60	.82	1.70	.57	1.14	.81	1.82	1.07	2.73
1875	.57	.56	1.02	1.00	1.41	1.13	1.50	2.03	.35	.81	2.28	1.68	2.28
1876	2.95	.66	1.04	1.90	.38	1.51	1.43	1.89	.61	2.64	.70	.45	2.95
1877	1.09	.39	2.13	.67	.49	1.39	1.24	.90	.82	.61	.97	1.41	2.13
1878	1.01	.59	1.83	1.19	.86	2.06	.94	1.22	.63	.57	1.35	.90	2.06
1879	.66	.95	1.70	.72	2.98	2.05	.62	2.68	1.75	.36	1.51	1.93	2.98
1880	1.16	1.81	1.39	1.93	2.18	3.12	1.54	1.88	.73	1.27	1.50	3.10	3.12
1881	1.27	1.50	.54	.89	1.21	1.90	1.74	.29	.94	2.29	1.67	1.60	2.29
1882	1.16	2.27	2.54	.56	2.47	1.26	.91	2.01	.78	.78	.46	1.10	2.54
1883	.78	1.96	1.73	1.32	1.76	.97	.72	.76	.91	3.06	2.23	2.60	3.06
1884	.49	2.50	.81	1.02	1.43	.69	.61	.87	1.31	.55	.52	1.27	2.50
1885	1.69	1.39	.18	.86	.45	.78	.40	2.62	1.25	.58	.92	.90	2.62
1886	.99	.55	.70	.58	1.28	1.68	.88	1.17	.36	.42	1.39	.71	1.68
1887	.77	2.98	.88	2.21	1.00	1.79	.58	.94	.57	.37	.81	.98	2.98
1888	.72	.50	1.27	.88	1.06	.57	.97	2.46	1.01	.63	1.35	.45	2.46
1889	.83	.60	.36	.98	1.54	1.14	2.40	.13	1.50	.95	1.10	.93	2.40
1890	1.33	1.24	1.06	1.09	1.16	1.55	1.16	2.66	1.60	1.25	.80	.72	2.66
1891	1.31	1.18	1.21	.44	.54	.96	2.43	.81	1.57	.75	1.59	.93	2.43
1892	1.62	2.83	.53	1.78	1.04	.96	.77	1.07	2.02	.17	.54	.68	2.83
Period	2.95	2.83	2.54	2.21	2.98	3.12	2.40	2.68	2.02	3.06	2.75	3.10	3.12

TABLE No. 24.—HEAVIEST RAINFALLS IN 24 HOURS AT ATLANTA, GEORGIA, 1879 TO 1892, INCLUSIVE.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1879	1.28	1.75	1.25	1.59	1.42	2.23	1.27	1.13	1.04	1.48	1.63	3.76	3.76
1880	1.10	2.10	1.71	1.78	2.56	1.16	1.14	.95	3.17	.76	2.19	1.33	3.17
1881	2.35	2.98	3.89	1.30	.57	.85	.20	1.54	2.12	2.66	.95	2.14	3.89
1882	1.23	1.69	1.66	2.11	.65	1.45	1.80	1.05	2.30	.55	1.49	1.30	2.30
1883	4.03	.58	.98	3.08	.99	.80	.46	.53	.38	1.06	1.89	1.27	4.03
1884	1.87	1.22	2.12	2.41	.42	1.42	.85	.84	.05	.39	.88	3.74	3.74
1885	1.56	1.18	1.79	.44	1.43	1.58	.98	4.22	1.64	1.38	1.18	1.25	4.22
1886	2.62	.33	7.36	1.24	2.77	1.69	1.13	.62	.34	.02	1.03	1.11	7.36
1887	1.05	.81	.50	.85	1.08	.65	3.51	1.51	1.86	1 06	.16	1.47	3.51
1888	1.24	1.34	1.76	.63	3.28	1.87	.73	.90	3.00	1.22	1.80	2.60	3.28
1889	1.16	1.65	1.18	1.26	1.68	1.27	2.32	1.80	2.00	.68	1.21	.41	2.32
1890	1.08	.98	1 20	.56	3.90	.43	2.17	.76	2.07	2.01	.09	1.65	3.90
1891	1.61	1.53	2.35	.83	.96	1.93	1.61	.59	.61	.02	1.43	.97	2.35
1892	3.28	1.28	2.01	3.19	.41	2.59	1.06	1.56	2.37	.34	1.71	1.57	3.28
Period	4.03	2.98	7.36	3.19	3.90	2.59	3.51	4.22	3.17	2.66	2.19	3.76	7.36

The two following tables, Nos. 25 and 26, show the actual length of time of a number of heavy rainfalls at two places in the Southwest, where very heavy rainfalls are common.

TABLE No. 25.—RAINFALLS IN EXCESS OF 2.5 INCHES IN 24 HOURS AT VICKSBURG, MISSISSIPPI, 1872 TO 1892, INCLUSIVE.

Dates.	Duration.		Amount.
	From	To	
April 2, 3, 1872	5.40 p.m.	9.50 a.m	2.62
April 5, 6, 1872	8.40 a.m.		3.33
May 23, 24, 1872	3.54 p.m.	9.35 a.m.	5.36
Dec. 18, 19, 1872	11.40 p.m.	1 p.m.	5.05
April 8, 1874	5.30 a.m.	4.45 p.m.	4.46
April 15, 1874	6 a.m.	6.15 p.m.	4.18
April 18, 19, 1874	3.30 p.m.	2.30 p.m.	4.86
July 4, 5, 1874	5.00 p.m.	4.30 p.m.	2.73
Sept. 25, 1874	4.15 p.m.	10.15 p m.	2.95
Jan. 23, 24, 1875	8.30 a.m.	during night	3.76
March 31, 1875	4.00 p.m.	9.40 p.m.	3.26
April 9, 10, 1875	8.30 p.m.	2.15 p.m.	2.63
Sept. 17, 18, 1875	7.45 a.m.		4.99
Nov. 28, 1880	during night	10.04 p.m.	2.93
Nov. 30, 1880	during night		
Dec. 1, 1880	during night		2.92
Dec. 19, 20, 1882	5.00 a.m.	12.30 a.m.	3.78
April 6, 1883	8.40 a.m.	3.45 p.m.	4.25
Nov. 10 & 11, 1883	during night	11.30 p.m.	4.79
Nov. 22, 1883	12.50 a.m.	2.55 p.m.	4.02
Dec. 29, 30, 1883	11 p.m.	9.20 p.m.	4.51
Sept. 3, 1884	1.45 p.m.	5.10 p.m.	2.69
Dec. 29, 1884	12.20 a.m.	1.30 p.m.	4.07
Jan. 15, 16, 1885	5.33 p.m.	8.30 p.m.	3.68
April, 6, 7, 1885	3.15 p.m.	7.00 a.m.	4.29
April 27, 28, 1886	7.20 a.m.	10.20 a.m.	2.79

TABLE No. 25.—Continued.

Dates.	Duration. From	Duration. To	Amount.	Dates.	Duration. From	Duration. To	Amount.
March 6, 1876......	11.45 a.m.	8.00 p.m.	2.84	Feb. 19, 20, 1887 ..	12.50 p.m.	during night	2.53
May 7, 1876........	during night	6.00 p.m.	3.40	Sept. 14, 15, 1881..	during night	6.20 a.m.	3.85
Dec. 23, 24, 1876...	11.45 a.m.	10.00 a.m.	3.70	Oct. 27, 28, 1881...	10.30 a.m.	3.10 p.m.	6.95
April 7, 8, 1877.....	8.10 a.m.	during night	3.53	Nov. 11, 1881......	12.30 p.m.	9.25 p.m.	3.32
Oct. 17, 18, 1877....	11.15 p.m.	9.40 p.m.	2.97	March 3, 4, 1888...	8.25 p.m.	8.00 p.m.	2.82
Nov. 1, 1877........	4.35 p.m.	8.45 p.m.	2.50	Aug. 19, 20, 1888..	11.50 p.m.	4.10 p.m.	2.75
Nov. 7, 8, 1877.....	3.35 p.m.	7.35 a.m.	2.83	June 11, 12, 1889..	Unknown		2.50
March 9, 1878......	8.30 a.m.	11.40 p.m.	4.46	Jan. 15, 1890......	6.50 a.m.	4.40 p.m.	2.53
April 23, 1878......	2.15 p.m.	12 midnight	2.63	March 11, 12, 1890.	10.30 p.m.	10.30 p.m.	2.73
Sept. 1, 2, 1879.....	8.25 a.m.	during night	3.97	May 2, 3, 1890.....	5.30 p.m.4,	30 p.m.	3.42
May 30, 1880.......	during night	9.45 p.m.	4.27	March 7, 8, 1891..	during night	during night	6.47
Oct. 4, 1880.... ..	during night	11.45 a.m.	2.71	Nov. 21, 22, 1891..	Unknown		4.28
Nov. 24, 25, 1880...	7.20 a.m.	8.00 a.m.	3.18	Feb. 19,20,1892....	Unknown		2.70

Dates on which 1.00 inch or more of precipitation occurred in one hour or less.

April 15, 1874......	3.30 p.m.	6.15 p.m.	3.40	Sept. 26, 1881....	3.45 p.m.	4.50 p.m.	1.31
May 23, 1879.......	5.38 p.m.	6.55 p.m.	1.42	July 17, 1888	5.00 p.m.	6.16 p.m.	1.38
June 13, 1879......	7.19 p.m.	8.15 p.m.	1.30	May 2, 1890......	5.45 p.m.	6.45 p.m.	1.20
Oct. 2, 1879........	5.25 p.m.	6.20 p.m.	1.25	May 3, 1890......	11.30 a.m.	12.30 p.m.	1.00
Nov. 28, 1879	4.00 a.m.	5.20 a.m.	1.81	July 8, 1890......	3.50 p.m.	4.40 p.m.	1.12
Aug. 17, 1880	3.30 p.m.	6.10 p.m.	2.22				

TABLE No. 26.—HEAVIEST RAINFALLS, WITH ACTUAL DURATION, AT SHREVEPORT, LOUISIANA, 1872 TO 1891, INCLUSIVE.

Date.	Duration. From	Duration. To	Amount.	Date.	Duration. From	Duration. To	Amount.
Jan. 5, 1872.....	9.30 a.m.	during night.	3.19	Nov. 8, 1881	During night	8.15 p.m.	2.50
May 23, 1872....	11.35 p.m.	10.35 p.m. 24″*	3.21	Dec. 13, 1881....	5.20 p.m.	3.00 p.m. 14″	2.55
Oct. 28, 1872....	8.05 p.m.	1.00 p.m. 29″	2.71	Dec. 19, 1881....	7.15 a.m.	7.00 a.m. 20″	2.72
Dec. 15, 1872....	11.15 p.m.	8.15 a.m. 16″	2.53	Feb. 2, 1882.....	4.30 p.m.	3.00 p.m. 3″	3.12
Nov. 22, 1873 ...	4.40 p.m.	4.40 p.m. 23″	4.00	July 18, 1882....	During night	5.45 p.m.	2.83
July 9, 1874.....	10.25 p.m.	11.50 a.m. 10″	3.36	Oct. 17, 1882....	11.00 p.m.	12.00 p.m. 18″	4.17
Aug. 9, 1875 ...	6.27 a.m.	6.27 a.m. 10″	2.62	Nov. 10, 1883 ...	8.00 a.m.	7.00 a.m. 11″	4.83
Sept. 17, 1875...	2.00 a.m.	2.00 a.m. 18″	7.00	May 21, 1884....	10.10 p.m.	8.40 a.m. 22″	5.45
Dec. 21, 1875. ..	10.50 p.m.	10.40 p.m. 22″	4.66	Nov. 22, 1884 ...	7.12 a.m.	7.20 p.m.	3.13
Mar. 11, 1876...	2.30 p.m.	6.30 p.m.	2.81	Dec. 27, 1884....	7.00 a.m.	7.00 a.m. 28″	2.83
Mar. 19, 1876 ...	10.00 a.m.	7.00 a.m. 20″	4.46	Dec. 28, 1884....	7.00 a.m.	7.00 a.m. 29″	4.08
May 6, 1876.....	3.30 p.m.	12.00 noon 27″	7.37	Dec. 29, 1884....	7.00 a.m.	7.00 a.m. 30″	3.78
Sept. 3, 1877....	8.30 p.m.	11.30 p.m.	6.87	Jan. 13, 1885....	11.00 p.m.	11.00 p.m. 14″	5.71
Mar. 8, 1878	7.00 p.m.	10.30 a.m. 9″	4.50	Jan. 14, 1885....	11.00 p.m.	8.30 p.m. 15″	4.27
April 15, 1878...	1.00 a.m.	9.00 a.m.	2.92	April 22, 18 5...	7.00 a.m.	7.00 a.m. 23″	4.16
July 23, 1878....	12.20 p.m.	5.00 p.m.	2.56	June 10, 1885...	3.00 p.m.	3.00 p.m. 11″	2.59
April 15, 1879...	2.45 p.m.	10.30 p.m.	4.64	Sept. 5, 1885 ...	11.15 a.m.	during night 6″	2.87
April 23, 1879...	1.48 p.m.	10.40 a.m. 24″	3.11	Oct. 25, 1885....	7.00 a.m.	7.00 a.m. 26″	2.98
Aug. 23, 1879 ...	9.53 p.m.	8.00 p.m. 22″	3.47	Mar. 26, 1886...	8.05 a.m.	7.30 a.m. 27″	2.71
Feb. 1, 1880.....	5.30 p.m.	3.00 p.m. 2″	3.00	Sept. 13, 1886 ..	12.20 a.m.	11.15 p.m.	2.73
April 28, 1880...	6.20 p.m.	5.54 a.m. 29″	2.55	Oct. 23, 1887....	10.30 p.m.	9.30 p.m. 24″	2.92
July 27, 1880....	3.30 p.m.	1.54 p.m. 28″	5.00	Nov. 24, 1887...	8.10 p.m.	8.10 p.m. 25″	2.90
Sept. 12, 1880....	6.35 a.m.	9.15 p.m	2.84	Dec. 6, 1887.....	3.00 p.m.	3.00 p.m. 7″	3.18
Feb. 5, 1881.....	1.00 p.m.	9 00 a.m. 6″	3.48	April 13, 1889...	10.15 a.m.	10.00 a.m. 14″	2.68
May 8, 1881.....	12.45 p.m.	9.10 p.m.	2.70	Nov. 6, 1889....	8.35 a.m.	8.35 a.m. 7″	2.57
Sept. 14, 1881...	During night	7.25 p.m.	4.06	Jan. 1, 1890,....	10.30 p.m.	10.30 p.m. 2″	2.62
Oct. 23, 1881....	During night	4.50 p.m.	2.63	Sept. 27, 1891...	10.40 p.m.	2.35 p.m. 28″	4.01
Oct. 27, 1881....	12.30 a.m.	6.20 p.m.	3.80	Dec. 22, 1891....	8.00 p.m.	6.30 p.m. 23″	4.64

* The minute (″) sign in this table indicates the day of the month when the rain stopped.

THE TIME OF OCCURRENCE OF MAXIMUM AND MINIMUM FLOW.

The foregoing tables indicate that there is a large variation in the flow of sewage from combined systems, by reason of irregular and uncertain accessions due to the rainfall. In such a system, the sewers, in a majority of cases presumably, will not be even approximately impervious ; the minimum quantity of flow will occur, probably, in times of drought, when not only infiltration from the surrounding soil is at its lowest, but leakage is at a maximum. On the other hand,

in separate systems, where the sewers have been made as nearly as possible absolutely impervious, assuming that roof water and cellar drainage are excluded, the maximum flow may be expected either in hot, dry weather, or in extreme cold weather, at both of which times the maximum consumption of water for domestic purposes will be taking place. Separate, or more properly, modified separate systems are, for sanitary reasons, frequently designed with reference to taking cellar drainage together with the whole, or a portion, of the roof water, and when so arranged the amount of the special inflows should be allowed for. In a discussion of this kind, as has been stated, no more can be done than to point out the main factors controlling, and the foregoing are enough to indicate the leading conditions in the problem to be solved.

By way of further illustrating the use of water for domestic and manufacturing purposes, Tables Nos. 27 and 28, showing the use of water in the city of Rochester, are included.

TABLE NO. 27.—TOTAL AVERAGE DAILY USE OF WATER IN GALLONS IN THE CITY OF ROCHESTER, N. Y., FOR THE YEARS INDICATED, THE POPULATION, ETC.

Hemlock Lake Water.				Average daily use of Holly water, per head of population, in gallons.	Total average daily use per head of population from both systems, in gallons.
April 1 to April 1.	Population.	Total average daily use, in gallons.	Average daily use per head of the population, in gallons.		
1876–7	83,600*	2,500,000	30.5	....	....
1877–8	85,150	3,280,000	38.9	....	....
1878–9	86,700	3,675,000	42.4	....	....
1879-80	88,430	4,510,000	51.0	....	....
1880–1	90,930	5,040,000	55.4	....	....
1881–2	93,100	4,925,000	53.0	....	....
1882–3	95,650	5,260,000	55.0	12.6†	67.6
1883–4	99,850	5,590,000	56.0	12.8	68.6
1884–5	104,200	6,160,000	59.1	12.4	71.5
1885–6	108,500	5,990,000	55.2	11.2	66.4
1886–7	113,900	6,660,000	58.5	11.9	70.4
1887–8	119,700	6,930,000	57.9	12.2	70.1
1888–9	126,500	7,250,000	57.3	12.5	69.8

* Official population in 1875, 81,722; in 1880, 89,366; in 1890, 133,896. No additions to territory during the period covered by this table. The reports for the years 1889–90, 1890–91, and 1891–92 do not give the consumption of Hemlock lake water with sufficient accuracy for inclusion here. The consumption of Holly water did not vary much from the above figures.

† Holly water in use from about January, 1874, but no record kept previous to the year ending April 1, 1883. The figures here given are based upon pump displacement with allowance for slip.

In explanation of these two Rochester tables it may be stated that the water works of that city are a dual system, including a gravity supply for purely domestic and special manufacturing purposes from Hemlock lake, while for other purposes, such as additional fire protection in the business district, street sprinkling, the furnishing of light power for motors, the flushing of water-closets in a few large blocks, water is taken from the Genessee river by a direct press-

TABLE NO. 28.—APPROXIMATE USE OF WATER FROM THE HEMLOCK LAKE SYSTEM, BY HOURS, ON THREE DIFFERENT DAYS IN 1890, AS DETERMINED BY THE OUTFLOW FROM THE MT. HOPE RESERVOIR OF THE WATER-WORKS OF ROCHESTER, N. Y.*

Hours.	7 a.m. to 7 p.m., Saturday, July 5, 1890 (12-hour period).		7 a.m. Sunday, Aug. 10, to 7 a.m. Monday, Aug. 11 (24-hour period).		7 a.m. Monday, Aug. 25, to 7 a.m. Tuesday, Aug. 26 (24-hour period).	
	Hourly outflow, gal.	Outflow in six hours, gal.	Hourly outflow, gal.	Outflow in six hours, gal.	Hourly outflow, gal.	Outflow in six hours, gal.
7 a.m. to 8 a.m.	330,563	....	217,907	....	392,041	....
8 " 9 "	374,220	....	260,911	....	355,035	....
9 " 10 "	394,238	....	277,490	....	389,125	....
10 " 11 "	366,163	....	285,393	....	386,659	....
11 " 12 "	392,583	....	250,098	....	333,590	....
12 m. to 1 p.m.	330,497	2,188,264	258,079	1,549,878	332,493	2,189,943
1 p.m. to 2 p.m.	373,238	....	248,800	....	348,811	....
2 " 3 "	363,562	....	239,670	....	330,245	....
3 " 4 "	345,789	....	204,907	....	277,078	....
4 " 5 "	345,877	....	161,936	....	345,676	....
5 " 6 "	341,381	....	212,638	....	292,693	....
6 " 7 "	326,262	2,096,109	204.707	1,272,658	291,818	1,886,321
7 " 8 "	....	....	169,426	....	205,479	....
8 " 9 "	....	....	186,026	....	143,816	....
9 " 10 "	....	....	151,926	....	170,626	....
10 " 11 "	....	....	118,004	....	170.326	....
11 " 12 "	....	....	151,505	....	102,063	....
12 p.m. to 1 a.m.	....	....	111,676	888,563	135,925	928,235
1 a.m. to 2 a.m.	....	....	67,222	....	135,685	....
2 " 3 "	....	....	134,146	....	101,643	....
3 " 4 "	....	....	150,757	....	118,485	....
4 " 5 "	....	....	100,326	....	135,204	....
5 " 6 "	....	....	217,105	....	185,607	....
6 " 7 "	....	....	266,463	936.019	286,080	962,704
Totals	4,284,373	4,284,373	4,647,118	4,647,118	5,967,203	5,967,203

* Tables Nos. 27 and 28 are from a paper by Mr. Rafter, On the Measures for Restricting the Use and Waste of Water in Force in the City of Rochester, N. Y., in Trans. Am. Soc. C. E., vol. xxvi., pp. 23–76. (January, 1892.)

ure Holly system. With this explanation the significance of table No. 27 will be easily understood.

In Table No. 28 we have the use of water from the Hemlock lake system by hours on three different days—namely, for Saturday, Sunday, and Monday. The Saturday record, unfortunately for really satisfactory comparison, is only complete for the 12 hours from 7 A. M. to 7 P. M. If we fill it out by comparison with the Monday record we see that in the summer of 1890 the use of water for all purposes from the Hemlock lake system was, on week days, roundly 6,000,000 gallons a day, or for a population of 133,896 (amount as per United States Census) we obtain a daily use of about 44.8 gallons. On Sunday, when manufacturing establishments are closed, the daily use of say 4,650,000 is equivalent to about 34.7 gallons per head of population per day. This latter figure may be considered as representing, therefore, approximately, the purely domestic use of water in the city of Rochester. The difference of 44.8 and 34.7, equal to 11.1 gallons per head, represents likewise the ordinary manufacturing use.

Examining the figures as to hourly flow we find the minimum to be

only 67,222 gallons per hour, amounting at this rate in 24 hours to 1,613,328 gallons. The maximum hourly flow of 394,238 gallons, amounts for 24 hours to 9,461,712. These figures are sufficient to show the considerable variation from the daily mean which will take place at different times of the day in a system where the amount of sewage is approximately represented by the amount of the water supply.

At the time of making these observations no water was used from the Hemlock lake system for either sprinkling streets or flushing sewers, and the figures may in consequence be taken as applying to the problem in hand without material correction or modification.

Results of Sewer Gagings.

So far as the authors are aware the most extended series of gagings of sewer discharges thus far made in this country are those of Samuel M. Gray, M. Am. Soc. C. E., at Providence, R. I.

Table No. 29, from Mr. Gray's Providence report, gives the results of a number of these gagings. In reference to the variations per inhabitant in different parts of the city Mr. Gray states that sewers laid in wet localities furnish a much greater quantity of sewage per inhabitant connected than do those laid in the drier part of the city; due, as already noted in Boston, in most localities to spring or ground water which thus finds its way into the sewers.

The daily use of water per capita in Providence is about 50 gallons, and the new intercepting sewers are designed to carry 60 gallons of sewage per inhabitant per day in addition to $\frac{1}{100}$ inch of rainfall per hour and the manufacturing wastes. The manufacturing wastes are estimated to flow off in ten hours; while one half of the sewage is estimated to flow off in seven hours.

In 1885 George S. Pierson, C. E., made a series of weir measurements of the flow of the Water street main sewer in Kalamazoo, Mich. Readings were taken on Monday, March 9, 1885, from 1 A. M. to 12 o'clock midnight. The minimum discharge occurred at 3 A.M. and amounted to 224 gallons per minute. The maximum, amounting to 287 gallons per minute, occurred at 4 P.M. The mean discharge for the whole 24 hours was 254 gallons per minute. Taking the mean discharge at 100, we have the minimum for the day 88 per cent. of the mean; the maximum 113 per cent. of the mean.*

In January, 1891, the flow of the main outfall sewer of the State Insane Hospital at Weston, W. Va., was gaged by weir measurement under the direction of Mr. Rafter for a period of 48 hours. This sewer is of vitrified tile, 12 inches in diameter, and probably as

* For detail of these gagings see The Separate System of Sewage, by Staley and Pierson.

TABLE NO. 29.—RESULTS OF WEIR MEASUREMENTS OF FLOW OF A NUMBER OF OUTFALL SEWERS IN PROVIDENCE, R.I., IN 1884.*

Street or lane.	Total present population.	People per house.	Houses connected.	Population connected.	Time when flow is above or below line of average flow.						Discharge while above or below line of average flow, gal.				Gallons per head of population connected.			Total meas. discharge per day.	Average discharge per second.	Maximum discharge per second.	Reference to date of measurements.
					Above.			Below.													
					Fr.	To.	Hrs.	Fr.	To.	Hrs.	Above.	%	Below.	%	Per day.	While above average line.	While below average line.				
Dorrance		8.5	772	6,562	7.42	7.0	11.18	7.0	7.42	12.42	412,089	65	220,744	35	96.44	62.79	33.64	732,833	7.32	11.65	Av. May, June.
Brook	6,178	7.88	575	4,480	6.48	5.12	10.24	5.12	6.48	13.36	226,440	44	284,504	56	114 05	50.50	60.50	510,944	5.92	6.78	Sat. Feb. 2.
"		"	"	"	6.30	3.06	8.36	3.06	6.30	15.24	200,434	41	284,670	59	108.28	44.74	63.54	485,107	5.61	6.78	Mon., Feb. 4.
"		"	"	"	7.00	7.30	12.30	7.30	7.00	11.30	200,862	58	144,612	42	77.03	44.84	32.19	345,474	3.985	5.47	Tues., July 1.
"		"	"	"	6.45	6.05	11.20	6.05	6.45	12.40	187,924	56	147,330	44	74.83	41.72	33.11	335,354	3.88	5.47	Thur. " 3.
"		"	"	"	6.26	8.15	12.15	...	...	11.45	193,464	58	140,148	42	74.47	43.19	31.28	333,612	3.86	5.76	Sat. " 5.
"		"	"	"	6.45	4.15	9.30	4.15	6.45	14.30	161,624	44	208,096	56	82.53	36.08	46.45	369,720	4.28	5.47	Mon. " 7.
Elm	12,536	7.9	1,114	8,800	7.15	5.15	10.00	5.15	7.15	14.00	208,305	58	150,200	42	40.76	23.69	17.07	358,705	4.15	7.90	Mon. Jan. 28.
"		"	"	"	7.0	5.30	10.30	5.20	7.0	13.30	188,406	59	130,726	41	36.27	21.41	14.86	319,132	3.69	7.90	Tues. " 29.
"		"	"	"	6.50	6.45	11.55	6.45	6.50	12.05	194,274	68	92,358	32	32.57	22.08	10.49	286,632	3.317	6.32	Wed., June 4.
"		"	"	"	7.03	7.28	11.34	...	...	12.26	202,266	69	88,828	31	33.08	22.99	10.09	291,094	3.37	6.32	Fri., " 6.
"		"	"	"	6.13	8.11	13.58	8.11	6.13	10.02	199,188	74	68,328	26	30.40	22.63	7.77	267.516	3.10	5.11	Thur., " 19.
No. Main	2,316	8.5	172	1,462	6.51	4.42	9.51	4.42	6.51	14.09	130,818	59	90,850	41	152.2	89.47	62.73	222.668	2.57	4.45	Mon., May 12.
"		"	"	"	6.50	5.20	10.30	5.20	6.50	13.30	116.304	54	96.432	46	145.5	79.55	65.95	212,736	2.46	3.80	Wed., " 7.
"		"	"	"	4.58	6.36	12.02	..	..	11.58	104,969	69	47,481	31	104.28	71.80	32.48	152,450	1.76	3.25	Fri., July 25.
Blackstone	12,529	7.8	606	4,727	6.00	5.30	11.30	5.30	6.0	12.30	83,628	64	46,312	36	27.49	17.69	9.80	129,940	1.50	3.20	Mon., Feb. 11.
"		"	"	"	6.30	4.26	9.56	4.26	6.30	14.04	155.214	73	56,394	27	44.76	32.83	11.93	211,608	2.40	5.40	Thur., " 14.
"		"	"	"	6.30	4.26	"	4.26	6.30	14.04	151,170	73	56,340	27	43.89	31.98	11.91	207,510	2.30	4.82	Sat., " 16.
"		"	"	"	7.30	4.45	9.15	4.45	7.30	14.45	79,977	44	98,367	56	37.73	16.94	20.79	178,344	2.06	2.65	Mon., " 18.
"		"	"	"	7.00	5.0	10.0	5.0	7.00	14.00	97.262	53	84,780	47	38.51	20.57	17.94	182.042	2.106	3.20	Fri., " 29.
Pitman	859	7.7	86	655	8.30	4.45	8.15	4.45	8.30	15.45	48,296	46	55,602	54	158.6	73.73	84.87	103,898	1.202	2.38	Mon., Apr. 28.
"		"	"	"	5.45	3.45	10.00	3.45	5.45	14.00	31,135	46	33,206	54	98.23	47.53	50.70	64,341	.744	1.38	Wed.. " 30.
Ives	3,397	8.89	204	1,814	6.36	4.45	10.09	4.45	6.36	13.51	34,199	52	30,817	48	35.84	18.85	16.98	65.016	.753	1.02	Mon., Mar. 3.
"		"	"	"	7.00	4.45	9.45	4.45	7.0	14.15	38,371	52	35.473	48	40.70	21.15	19.55	73,844	.854	1.36	Wed., " 5.
"		"	"	"	7.45	7.45	10.12	..	..	13.48	33,318	55	22,778	45	33.12	18.36	14.76	60,096	.695	1.30	Mon., Aug. 25.
"		"	"	"	6.45	8.20	13.39	..	..	10.21	33.441	64	18,420	36	28.58	18.43	10.15	51,861	.60	.92	Wed., " 27.
College	1,164	7.7	108	824	6.45	9.00	13.15	7.0	6.45	10.45	59,409	65	31,983	35	110.91	72.09	38.82	91,392	1.05	1.82	Fri., May 2.
"		"	"	"	7.00	11.	11.0	5.0	7.0	13.00	51.912	56	40,248	44	111.84	63.00	48.83	92.160	1.07	1.81	Mon., " 5.
Point	3,738	8.5	321	2,729	10.	5.00	13.45	8.30	6.45	10.15	94,788	69	41,004	31	49.75	34.73	15.02	135.792	1.57	3.82	Mean, May 6–21.
Power	265	7.7	31	239	6.0	8.15	14.15	8.15	6.0	9.4	16,073	72	6,122	28	92.86	67.25	25.61	22,195	.26	.56	Wed., Apr. 23.
"		"	"	"	6.0	8.30	14.30	8.30	6.0	9.30	16,138	73	5,906	27	92.23	67.52	24.71	22,044	.26	.54	Fri., " 25.
"					6.40	8.30	12.24	..	..	11.36	3,174	80	788	20	16.16	13.28	2.88	3,962	.045	.14	Fri., Aug. 22.
Nash	394	7.7	25	193	5.30	8.00	11.20	..	..	12.40	2,066	63	1,214	37	17.00	10.70	6.29	3,280	.037	.135	Mon., Apr. 21.
"		"	"	"	"	"	11.06	..	..	12.54	1,580	60	1,056	40	13.66	8.20	5.46	2,636	.030	.06	Tues., " 22.
"					"	"	12.39	..	..	11.21	2,423	76	736	24	16.36	12.55	3.81	3,159	.036	.086	Wed., Aug. 6, 7, 11.
Park	276	7.7	21	162	7.15	8.45	10.24	..	..	13.36	1,950	65	1,027	35	18.37	12.04	6.33	2,977	.034	.187	Fri., Apr. 18.
"		"	"	"	7.0	8.30	7.10	..	..	16.50	3,102	83	606	17	22.88	19.14	3.74	3,708	.043	.385	Mon., Aug. 18.
Martin	1,801	7.7	153	1,178	8.0	9.30	13.30	9.30	8.0	11.30	68,760	66	35,615	34	88.60	58.37	30.23	104,375	1.208	1.40	Wed., July 9.

* A portion of the original table has been omitted.

nearly absolutely impervious as such a sewer can be made. An examination of the joints at a number of test pits indicated that neat or nearly neat Portland cement had been freely used in making the joints, every one examined showing the bells well filled, with large wads of cement under and around the joints.

The tributary population at the Hospital, including patients, officers, attendants, and servants is almost exactly 1,000. In addition to sewage proper the sewer receives some roof water, but at the time of making the gagings there was neither rainfall nor melting snow to contribute from this source. The sewer received the water of condensation from the steam heating apparatus of the Hospital, amounting in January to about 10,000 gallons per day. Aside from this addition the results may be taken as representing the normal amount of sewage of the institution. Self-closing fixtures are in use throughout the building, and no serious sources of leakage from the water fixtures could be discovered. The total mean flow for 24 hours was found to be 101,047 gallons; the maximum, amounting to 6,696 gallons per hour, occurring between 9 and 10 A.M.; the minimum, of 2,079 gallons per hour, occurred between 1 and 2 A.M. Deducting the estimated water of condensation of 10,000 gallons per day there remains the sewage proper, about 91,000 gallons per day, which, for a tributary

TABLE No. 30.—RESULTS OF A GAGING BY WEIR MEASUREMENT OF THE FLOW OF MAIN OUTFALL SEWER OF THE STATE INSANE HOSPITAL AT WESTON, WEST VIRGINIA, IN JANUARY, 1891.

Day.	Hour.	Rate in gallons per minute.	Mean flow in gallons per hour.	Day.	Hour.	Rate in gallons per minute.	Mean flow in gallons per hour.
Wednesday	12 M.	78.75	5,170	Thursday	12 M.*	93.60	5,792
	1 P.M.	93.60	5,616		1 P.M.	99.45	5,576
	2 “	93.60	5,070		2 “	86.40	5.400
	3 “	75.60	4.536		3 “	93.60	5,076
	4 “	75.60	4,374		4 “	75.60	5,076
	5 “	70.20	4,374		5 “	93.60	5,238
	6 “	75.60	4,536		6 “	81.00	5.238
	7 “	75.60	4,374		7 “	93.60	4.563
	8 “	70.20	3,861		8 “	58.50	3,362
	9 “	58.50	3,361		9 “	53.55	3,362
	10 “	53.55	2,943		10 “	53 55	2,943
	11 “	44.55	2,673		11 “	44.55	2,673
	12 “	44.55	2.673		12 “	44.55	2.376
Thursday	1 A.M.	44.55	2,673	Friday	1 A.M.	34.65	2,079
	2 “	44.55	2,673		2 “	34.65	2,228
	3 “	44.55	2,673		3 “	39.60	2.659
	4 “	44.55	2,806		4 “	49 05	2,943
	5 “	49.05	3,415		5 “	49.05	3,227
	6 “	64.80	4,212		6 “	58.50	3.861
	7 “	75.60	4,860		7 “	70.20	4.698
	8 “	86.40	5,751		8 “	86.40	5,751
	9 “	105.30	6.696		9 “	105.30	5,751
	10 “	117.90	6,345		10 “	86.40	5,184
	11 “	93.60	5,616		11 “	86.40	5,751
	12 M.*	93.60			12 M.	105.30	

* Repeated.

population of 1,000, amounts to 91 gallons per day. Table No. 30 gives the details of these gagings.

In February, 1892, William B. Landreth, M. Am. Soc. C.E., gaged the flow of the main sewer of Schenectady, New York, for a period of 24 hours. The main outfall sewer of Schenectady receives the drainage from about 15 miles of lateral sewers, of the separate system, having 1,500 house connections.

At the time of the gagings no roof water was flowing into the sewers, but they were receiving 50,000 gallons in 24 hours of flush-tank discharge and 60,000 gallons by seepage, as determined before the house connections were made.

Table No. 31 gives the results.*

TABLE No. 31.—HOURLY FLOW AND PERCENTAGE OF THE SAME OF THE TOTAL FLOW IN THE MAIN SEWER AT SCHENECTADY, NEW YORK, FOR 24 HOURS.

Feb. 5, 1892. Hour.	Hourly flow, gallons.	Per cent. of total flow.	Feb. 5, 1892. Hour.	Hourly flow, gallons.	Per cent. of total flow.
9 A.M.	39,800	4.63	10 P.M.	33,884	3.94
10 "	43,352	5.04	11 "	33,884	3.94
11 "	37,475	4.36	12 "	32,718	3.80
12 M	37,475	4.36	Feb. 6.		
1 P.M.	38,632	4.49	1 A.M.		
2 "	39,800	4.63	2 "	32,718	3.80
3 "	41,073	4.78	3 "	32,718	3.80
4 "	38,632	4.49	4 "	30,294	3.52
5 "	37,475	4.36	5 "	32,718	3.80
6 "	36,423	4.23	6 "	31,416	3.65
7 "	36,423	4.23	7 "	31,416	3.65
8 "	36,423	4.23	8 "	34,044	4.00
9 "	33,884	3.94		36,423	4.23

From this table it appears that the greatest flow was at 10 A.M., when 5.04 per cent. of the total daily flow of about 860,000 gallons was passing through the sewer. The minimum flow of 3.52 per cent. occurred at 3 A.M.

Comparing the Schenectady gagings with those at the Weston Asylum, it appears that both the maximum and minimum flows occurred later at Schenectady than at Weston, which is probably accounted for largely by the greater distance which the sewage travelled at Schenectady.

In the spring of 1891 gagings were made of the flow of sewage in several sewers at Toronto, Ont. The gagings extended over three days. The results are given in Table 31A.†

*Eng. News, vol. xxvii., p. 305 (March 26, 1892).

† Eng. News, vol. xxviii., p. 499 (Nov. 24, 1892). This table originally appeared substantially as here given in the report of the City Engineer of Toronto, Ont., for 1891.

TABLE 31A.—SEWER GAGINGS AT TORONTO, ONTARIO, IN 1891.

Size of sewer.	Area drained above weir, acres.	Population.*		Discharge in				
		Per acre.	Total.	Cubic feet per minute.	Cubic feet per acre per min.	Cubic feet per head per day.	Cubic feet per day.	Gallons per head per day.
7 ft. 6 ins. diam.	2,485	15.7	39,014	278.09	.11	10.27	400,450	77
3 " 6 " × 5 ft. 0 ins.	372	46.2	17,186	212.28	.57	17.78	305,683	133
3 " 9 " × 2 " 6 "	360	8.8	3,168	31.30	.09	11.07	45,072	83
2 " 0 " × 3 " 0 "	13	44.0	572	16.74	1.29	42.14	24,105	316
2 " 6 " × 5 " 0 "	101	45.5	4,595	32.65	.32	10.23	47,016	77
2 " 0 " × 3 " 0 "	25	41.8	1,045	10.89	.43	15.00	15,682	113
3 " 9 " × 2 " 6 "	350	17.6	6,160	57.50	.16	13.44	82,800	101
3 " 9 " × 2 " 6 "	263	42.3	11,125	71.56	.27	9.26	103,046	69
2 " 8 " × 4 " 0 "	160	39.8	6,368	67.20	.42	15.19	96,768	113
6 " 6 " × 5 " 0 "	195	42.4	8,268	62.62	.32	10.90	90,168	89
6 " 6 " diam.	740	11.8	8,732	82.25	.11	13.56	118,440	102
3 " 6 " × 5 ft. 0 ins.	225	43.7	9,832	80.83	.36	11.84	116,395	89
2 " 8 " × 4 " 0 "	271	41.7	11,300	70.94	.26	9.04	102,153	68
2 " 4 " × 3 " 6 "	770	9.4	7,238	70.57	.09	14.04	101,616	105
4 " 0 " × 5 " 6 "	311	45.7	14,213	117.10	.38	11.86	168,624	89
4 " 3 " diam.	503	38.3	19,265	93.78	.19	7.02	135,043	53
Averages	......	24.0	......	.....	.200	11.62	....	87
Totals	6,794	....	168,081	1,356.30	...	......	1,953,061	...

* Estimated from assessments of 1890 and census of 1891.

A YEAR'S DAILY SEWAGE PUMPING RECORDS AT ATLANTIC CITY, NEW JERSEY.*

One of the most valuable contributions to the subject under discussion is the daily sewage pumping records in connection with the sewage purification works at Atlantic City, New Jersey, given in full for one year and discussed in detail below.

Daily records of pumpage and coal consumption are kept by the Atlantic City Sewerage Company. The pump register is read at 12 M. each day, allowances being made for slip and wear of the plunger. The diagram, Plate II., shows the pumpage of sewage for each day from December 1, 1891, to November 30, 1892. The diagram also shows the rainy days of the year, and the maximum and minimum temperature of each month, by dates. The figures from which the diagram was compiled are given to the nearest thousand in Table 31B. Sundays and rainy days are indicated both in Table 31 B, and the diagram, Plate II.

For an understanding of the diagram and the accompanying tables, it is necessary to state that there are two seasons at Atlantic City, a winter and a summer. The winter season begins about January 15, and is said to continue often until June 15, when the summer season opens. In July and August, 1892, it is said that the average population was 100,000. The resident population is at present about 15,000.

* Rearranged from Eng. News, vol. xxix. pp. 123–124 (Feb. 9, 1893).

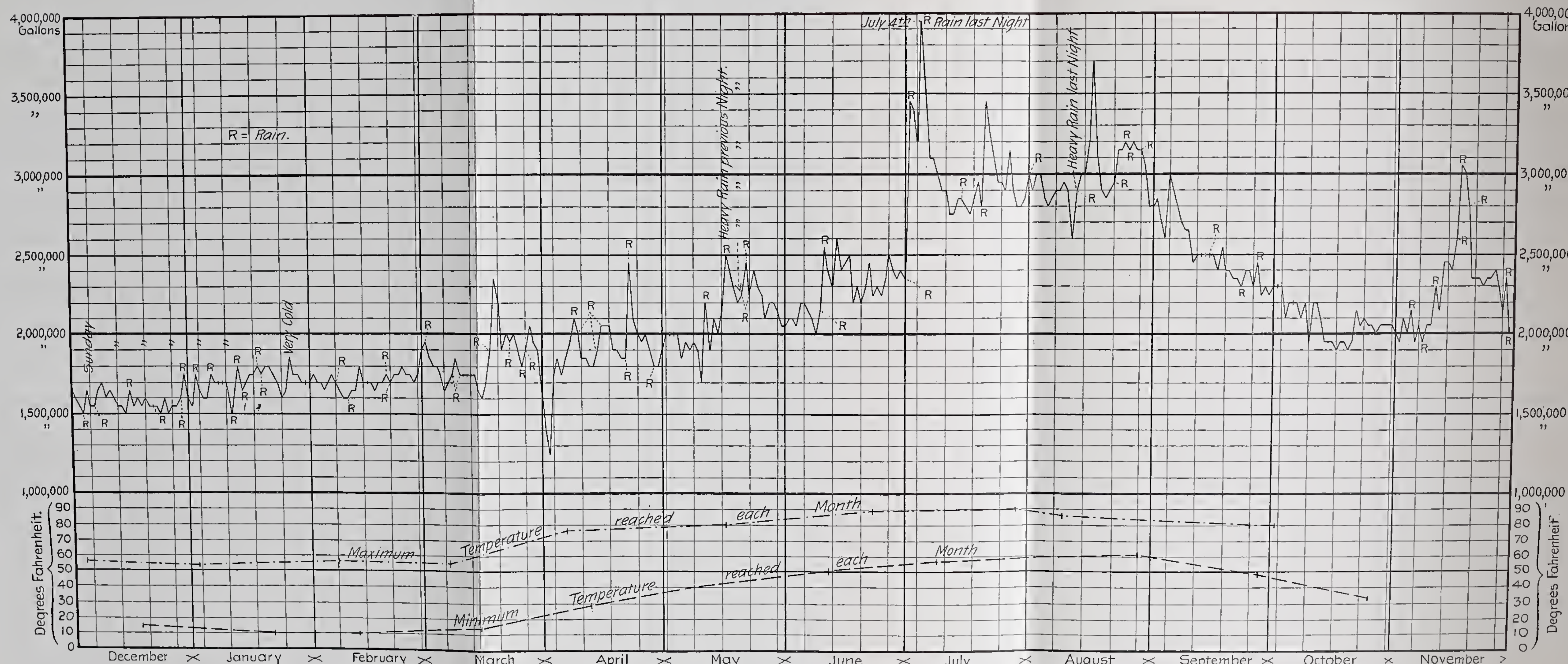


PLATE II. DAILY PUMPAGE OF SEWAGE AT ATLANTIC CITY, NEW JERSEY, FROM DEC. 1, 1891, TO NOV. 30, 1892.

Table No. 31 B.—Daily Pumpage of Sewage in Thousands of Gallons at Atlantic City, New Jersey, from Dec. 1, 1891, to Nov. 30, 1892.

Day of month.	December.	January.	February.	March.	April.	May.
1	1,642	1,549	1,728	1,940 R	1,410	1,998 S
2	1,604	1,749 R	1,711	1,872	1,229	1,996
3	1,529	1,643 S	1,681	1,824	1,760 S	2,002
4	1,509 R	1,625	1,673	1,807	1,842	1,997
5	1,638	1,615	1,719	1,767	1,762	1,832
6	1,560 S	1,740 R	1,757	1,647 S	1,871	1,966
7	1,547 R	1,702	1,682 SR	1,705	1,965	1,897
8	1.670	1,694	1,633	1,740 R	2.083 R	1,974 S
9	1,698	1,681	1,621	1,845	2,012 R	1.893
10	1,612	1,722 S	1,623 R	1,751 R	1,858 S	1,710
11	1,662	1,504 R	1,651	1,743	1,826	2,214 R
12	1,598	1,665	1,632	1.758	1,822	1,920
13	1,561 S	1,794 R	1,790	1,745 S	1,818	2,082
14	1,559	1,649 R	1,694 S	1,732	1,911 R	1,979
15	1,509	1,712 R	1,709	1,651	2,057 R	2,165 S
16	1,637 R	1,751	1,693	1,604	2,062	2,515 R^1
17	1,530	1,728 S	1.655	1,678	2,034 S	2,401
18	1,602	1,777 R	1.681	1,892 R	1,921	2,275
19	1,530	1,739 R	1,725	2,328	1,922	2,184
20	1,585 S	1,807	1.726 R	2,208 S	1,847	2.271 R^1
21	1,561	1,796	1,676 SR	1,920	1,851 R	2,427 R
22	1,542	1,740	1,746	2,004	2,451 R	2,260 SR
23	1.540	1,712	1,728	1,932 R	2,087	2,382
24	1,503 R	1,608 S	1,792	1,974	1.985 S	2,304
25	1,579	1.634	1,765	1,917	1,933	2,264
26	1,507	1,830	1,750	1,824 R	1,989	2,097
27	1,527 S	1,742	1,708	1,892 SR	1,911	2,191
28	1,563	1,739	1,728 S	2.074	1,821	2.216
29	1,616 R	1,721	1,874	1,933	1,801 R	2,132 S
30	1,758 R	1,700	.....	1,889	1,896	2,029
31	1,623	1,680 S	.....	1.824	.....	2,048
Total	49,100*	52,748	49,556	57,419	56,735	65,622
Average	1,584	1,701	1,709	1,852	1,891	2,117

Day of month.	June.	July.	August.	September.	October.	November.
1	2,116	3,456 R	2,925	2,851	3,212	1,941
2	2,083	3.390	2.979	2,721	2,250 S	2,087
3	2,064	3,185 S	2,999	2,614	2,120	1,990
4	2,179	3,938 R^2	2,862	3,001 S	2,208	2,133 R
5	2,218 S	3,498	2,822	2,897	2,208	1,932
6	2,133	3,106	2,837	2.797	2,200	2,026 S
7	2,112	3,087	2,880 S	2,681	2,101	1,928 R^2
8	2,018	2,995	2,897	2,663	2,207	2,059
9	2,170 R	2,879	2.936	2,657	1,949 S	2,070
10	2,537 R	2,877 S	2,907	2,444	2,175	2,298 R
11	2,382	2,730	2,608	2,517 S	2,187	2,144
12	2,309 S	2,756	2.922 R^1	2,475	2,119	2,472
13	2,602	2,852	2,976	2,477	1,958	2,550 S
14	2,416	2,874 R	3,004 S	2,515 R	1,947	2,419
15	2,442	2,820	3.181	2,486	1,933	2,600 R
16	2,509	2,762	3,699	2,400	1,920 S	3.073 R
17	2,180	2,865 S	3,083	2,551	1,941	2,999
18	2,291	2,927	2,915	2,392 S	1,950	2.819 R
19	2,214 S	2,775 R	2,854	2,382	1,889	2,358
20	2,293	3,466	2,912	2,338	1,952	2,374 S
21	2,453	3,264	2,968 SR	2,347	2.168	2,362
22	2,271	3,091	3,147	2,313 R	2.037	2,313
23	2,293	2,967	3,135	2.391	2,101 S	2,332
24	2,237	2,955 S	3,207 R	2,389	2,061	2,343
25	2,355	2,890	3.168 R	2,289 S	2,069	2,380
26	2,485 S	3.153	3.209	2,475 R	2,020	2,297
27	2,387	2,881	3.128	2,244	2,029	2.141 S
28	2,368	2,821	3,150 SR	2,285	2.074	2,351 R
29	2,388	2,811	3,054	2,231	2,049	2,009 R
30	2,369 R	2,865	2,813	2,278	2,014 S	2,019
31	.....	2,998 SR	2,820	.....	1,994	.....
Total	68,870	93.935	92.997	75,102	64,171	68,719
Average	2,296	3,030	3,000	2,503	2,070	2,291

S = Sunday. R = Rain. R^1 = Heavy rain previous night. R^2 = Rain previous night.

* Footings may not correspond exactly with totals given, as former include the odd figures omitted from hundreds column.

It is stated that there are over 600 hotels and boarding-houses and nearly 4,000 houses in the city.

That not all of the buildings are supplied with water, and that all so supplied are not connected with the sewers, is shown by the following figures:

	Number of taps.			No. of sewer connections.	Excess of water over sewer connections.	
	Atlantic City W. W. Co.	Consumers' Water Co.	Total.		Number.	Per cent.
December, 1891	2,273	500	2,773	1,849	924	50
December, 1892	2,468	500	2,963	2,140	823	38

The relative average daily amounts of water consumed and of sewage pumped from December 1, 1891, to November 30, 1892, are shown in Table 31 C, the figures for the Consumers' Water Company not being based on accurate records, but being estimated by the engineer of the company for use in this connection.

These figures show that the excess of average daily water consumption over sewage pumped ranged from 11 per cent. in July to 75 per cent. in September, and averaged 45 per cent. for the year. As stated above, there were 50 per cent. more water taps than sewage connections at the beginning of the year, and 38 per cent. at its close. The relative monthly consumption of water and pumpage of sewage is also shown graphically by the diagram, Fig. 6.

TABLE 31 C. — AVERAGE DAILY WATER CONSUMPTION AND SEWAGE PUMPAGE BY MONTHS, AT ATLANTIC CITY, NEW JERSEY, FROM DEC., 1891, TO NOV., 1892.

Month.	Average daily consumption of water.			Average daily sewage pumpage.	Excess water over sewage.	
	Atlantic City W. W. Co.	Consumers' Water Co.	Total.		Amount.	Per ct.
December	1,863,575	330,000	2,193,575	1,583,867	609,708	32
January	1,960,374	380,000	2,340,374	1,701,537	638,837	37
February	2,162,669	450,000	2,612,669	1,708,832	903,837	53
March	2,376,137	470,000	2,846,137	1,852,237	993,900	54
April	2,543,735	500,000	3,043,735	1,891,182	1,152,553	61
May	3,006,077	480,000	3,486,077	2,116,843	1,369,234	64
June	2,604,730	518,000	3,122,730	2,295,652	827,078	36
July	2,815,731	550,000	3,365,731	3,030,156	335,575	11
August	3,550,273	540,000	4,090,273	2,999,913	1,090,360	36
September	3,854,781	535,000	4,389,781	2,503,404	1,886,377	75
October	2,919,584	520,000	3,439,584	2,070,024	1,369,560	66
November	2,232,419	475,000	2,707,419	2,290,624	416,795	18
Year	....	....	3,142,682	2,172,059	970,623	45

The greatest amount of sewage pumped in any one day during the year was 3,937,720 gallons, which, it is interesting to note, was on July

5, on which date a large crowd of people generally visits the city. The least pumpage on one day was on April 2. The maximum and minimum daily pumpage for each month in the year, with the date of the same, and also the variation between the two, the average for the

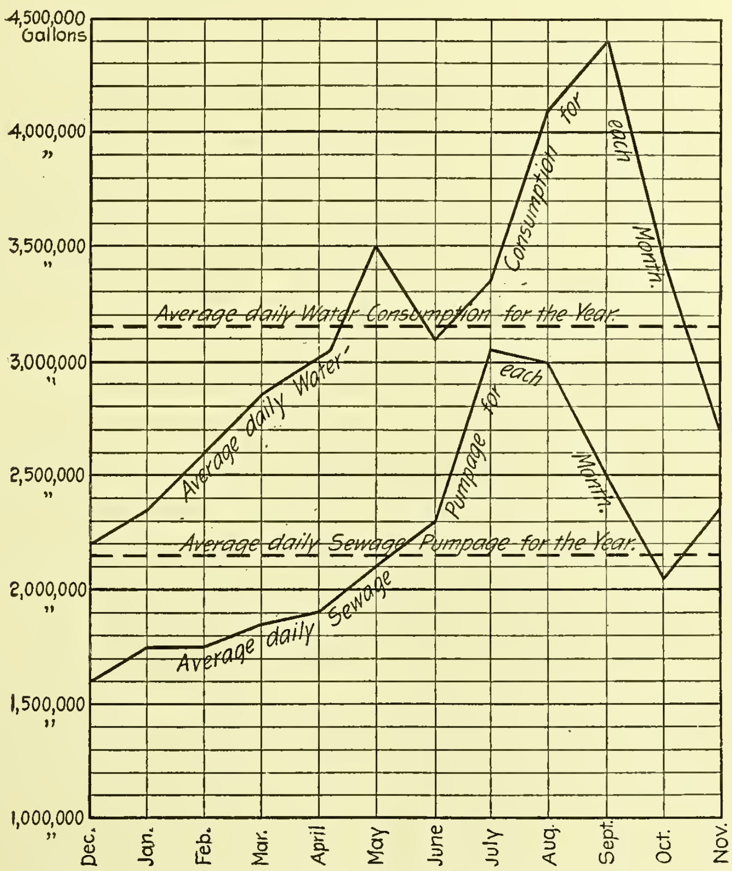


FIG. 6.—AVERAGE DAILY WATER CONSUMPTION AND SEWAGE PUMPAGE, BY MONTHS, AT ATLANTIC CITY, NEW JERSEY.

month and the number of sewer connections on the first of each month, are shown by Table 31D.

It will be seen by referring to the diagram, Plate II. and Table 31 B, showing each day's pumpage for the year, that nearly every rainy day was accompanied or followed by an increase in the amount of sewage. The foot notes to Table 31D show that for six months of the twelve the maximum pumpage was preceded or accompanied by rain, but the same was true of the minimum pumpage of three of the

TABLE 31D.—MAXIMUM AND MINIMUM DAILY PUMPAGE OF SEWAGE, BY MONTHS, AT ATLANTIC CITY, NEW JERSEY, FOR THE YEAR ENDING WITH NOVEMBER, 1892.

Month.	No. sewer connections first of each month.	Average.	Maximum.		Minimum.		Variation.
			Amount.	Date.	Amount	Date.	
December	1,849	1,583,867	1,757,760[1]	30	1,502,592[1]	24	255,168
January	1,887	1,701,537	1,830,432[2]	26	1,503,744[3]	11	326,688
February	1,892	1,708,832	1,873,728	29	1,620,672	9	253,056
March	1,910	1,852,237	2,328,192[4]	19	1,603,584	16	714,608
April	1,912	1,891,182	2,450,784[1]	22	1,228,896	2	1,221,888
May	1,961	2,116,843	2,515,584[5]	16	1,710,112	10	805,472
June	2,004	2,295,652	2,601,888	13	2,017,728	8	584,160
July	2,035	3,030,156	3,937,720[6]	4	2,730,144	11	1,207,576
August	2,051	2,999,913	3,699,344	16	2,607,744	11	1,091,600
September	2,061	2,503,404	3,001,440	4	2,230,656	29	770,784
October	2,081	2,070,024	2,312,160	1	1,888,512[8]	19	423,648
November	2,109[7]	2,290,624	3,072,864[1]	16	1,937,584	7	1,145,280
Year	.....	2,172,059	3,937,720	..	1,228,896	..	1,708,824

[1] Rain on this and preceding days. [2] Very cold. [3] Rain. [4] Rain previous day. [5] Heavy rain previous night. [6] Rain previous night. [7] 2,140 on Dec. 1, 1892. [8] Rain in night.

twelve months, though no heavy rains are mentioned in connection with minimum as with maximum pumpage. The separate system of sewers is in use at Atlantic City, with a few roof connections, principally for flushing. Some leakage would be expected under the most favorable circumstances, and some actually occurs, as shown above. The maximum pumpage for January occurred on a day reported in the pumpage records as "very cold."

In order to see what, if any, effect temperature had upon the amount of sewage, the maximum and minimum temperatures of each month were compiled from the United States Monthly Weather Review, as given in Table 31E, and then plotted on the diagram, Plate II. Low temperatures in winter, through waste of water to keep plumbing from freezing, and high temperatures in summer, might be expected to

TABLE 31E.—MONTHLY TEMPERATURES AND PRECIPITATION AT ATLANTIC CITY, NEW JERSEY, FOR THE ELEVEN MONTHS ENDING WITH OCTOBER, 1892.

Month.	Degrees F.								
	Max.	Date of max.	Min.	Date of min.	Mean max.	Mean min.	Mean max. and min. ÷ 2.	Precipitation, ins.	Av. daily sewage pumpage.
December	56	4	15	18	48	34	41.0	3.19	1,583,867
January	53	2	10	21	39	26	32.5	3.02	1,701,537
February	57	8	10	13	40	29	34.5	1.43	1,708,832
March	55	7	14	15	42	28	35.0	3.69	1,852,237
April	76	6	28	12	53	40	46.5	3.05	1,891,182
May	80	16	40	8	64	51	57.5	5.51	2,116,843
June	89	22	51	11	74	63	68.5	4.44	2,295,652
July	90	28	57	8	76	64	70.0	4.23	3,030,156
August	86	9	61	28	79	68	73.5	3.26	2,999,913
September	80	25	48	27	72	59	65.5	1.08	2,503,404
October	80	1	33	25	63	47	55.0	0.30	2,070,024

cause an increase in the amount of sewage, and doubtless do; but the figures compiled and plotted have a bearing upon only two days in each month, and are of little or no help in the study. Unfortunately, the Weather Review does not give daily temperatures, which would be of interest and value in this connection. As showing something of the temperatures of the whole of each month, the mean maximum, mean minimum, and the half of the sum of the two, are given below for the year, in connection with the maximum and minimum temperatures and their dates. The total monthly precipitation and the average pumpage of sewage for each month is also given at the right. The figures for November were not available.

The cold weather during the first part of January, 1893, seems to have had a marked effect upon the amount of sewage, the temperature and pumpage for each of the first 20 days of the month having been as follows, the thermometer and pump register being read at 12 m. each day:

	Temperature, degrees F.	Pumpage, gallons.		Temperature, degrees F.	Pumpage, gallons.
January 1	40	2,179,584	January 12	22	2,393,168
2	38	2,199,936	13	9	2,401,344
3	29	2,194,944	14	12	2,497,162
4	18	2,250,528	15	18	2,304,960
5	24	2,143,776	16	4	2,295,360
6	24	2,152,472	17	6	2,312,352
7	18	2,173,632	18	10	2,343,360
8	22	2,191,776	19	21	2,246,208
9	24	2,208,288	20	16	2,264,160
10	14	2,263,968			
11	7	2,326,272	Total		45,343,250
			Averages	19	2,267,163

The average daily pumpage for January, 1892, was 1,701,537, against 2,267,163 for the first 20 days of January, 1893, and 2,172,059 for the year ending November 30, 1891. The number of sewer connections increased only about 16 per cent. between January, 1892, and January, 1893, while the daily amount of sewage pumped in the first 20 days of January, 1893, was about 33 per cent. greater than the average for January, 1892. For the year ending November 30, 1892, the lightest pumpage was in the month of January. From these figures it appears that the cold weather of January, 1893, greatly increased the amount of sewage at Atlantic City, although there may have been other causes contributing to the increase, such as an unusually large number of visitors in the city, although at this season of the year the latter supposition seems hardly probable.

CHAPTER VIII.

GENERAL DATA OF SEWAGE DISPOSAL.

The Constituents of Sewage.

Ordinary city sewage contains a great variety of ingredients, as, for instance, urine, fæces, table droppings, and the waste water from kitchens, baths, laundries, and other domestic offices. In manufacturing districts it may further contain the refuse substances of various manufacturing processes, the whole diluted with a considerable amount of water, to which in rainy weather is added, in towns with combined systems, a large amount of sand, earth, and organic matter from the surfaces of the streets. With a separate system of sewers the street washings are excluded, and the sewage has in consequence a more permanent character than is found in the sewage from combined systems. Sewage from separate systems may be therefore considered somewhat more amenable to economical treatment than that from combined systems, not only because of its permanent character, but by reason of uniformity of quantity; both considerations leading to decrease in first cost of disposal works as well as to decrease in annual expense of operation.

Sewerage Systems—Separate or Combined.

The relative advantages of the two systems of sewerage have been ably discussed in American sanitary literature by Eliot C. Clarke, M. Am. Soc. C.E., and Col. Geo. E. Waring, Jr., M. Inst. C.E.,* and others, and the subject will be pursued no further here than to point out that the recent extensions of knowledge of the causation of typhoid fever and the other water-borne communicable diseases enforce, somewhat, the argument for separate systems wherever they are applicable, by reason of the greater amenability of the sewage therefrom to purification treatment.

In the chapter on The Infectious Disease of Animals it has been shown that the excrements of animals are nearly as prejudicial as those

* The Separate System of Sewerage. By Eliot C. Clarke, 2d An. Rept. Mass. St. Bd. Health, Lunacy and Charity, Supp. 1880, pp. 25-44.

Sewerage and Land Drainage. By Geo. E. Waring, Jr., etc., Chapter III, The System, Combined or Separate, pp. 28-53.

of man; and with this premise admitted it would appear at first sight that the force of the argument in favor of separate systems is considerably modified, in consequence of the large amount of animal excrements which must be inevitably washed from the street surfaces into the clean water conduits with every rainfall. This objection has some force, though less than may appear at first sight. To begin with, paved streets are frequently cleaned, and in places where this work is only negligently done a more rigid administration of street cleaning departments may be relied upon to assist in reducing the evil. Again, it must be remembered that absolute immunity from danger cannot be hoped for; there will always be some risk, even after the best has been done that is possible in any given case. Moreover, so far as public water supplies are concerned, the true remedy lies in the direction of an absolutely uncontaminated source.

In regard to the treatment of storm water, the Rivers Pollution Commission, after reciting the standards which they propose for liquids deemed polluting and inadmissible to any stream, say: *

> The enforcement of these standards of purity would, as we have repeatedly stated, inflict no serious injury upon industrial processes and manufactures, nor would the remedies required involve any risk to the public health; nevertheless there is, in the case of town sewage, a condition of things which ought, in our humble opinion, to be taken into careful consideration in the framing of a legislative enactment. The condition to which we allude is that caused by excessive rainfall, or "storm water," as it is technically called. To provide for the exceptional occasions when this condition prevails would entail in many cases an expenditure, in sewerage works, many times greater than that necessary in ordinary weather. We are therefore of opinion that, however undesirable, it will be necessary to permit storm water to flow directly into rivers and streams without preliminary cleansing. Unfortunately, chemical analysis shows that storm water, so far at least as its earlier portions are concerned, is more polluting than dry weather sewage, owing to old deposits in the sewers being then swept to the outfall; and it will be very important, therefore, to guard against any unnecessary use of this exceptional permission.

On the question of separation of sewage from rainfall and the relation of such separation to purification treatment, Eliot C. Clarke writes as follows in his report to the Massachusetts Drainage Commission:

> So long as it was considered sufficient to put sewage as well as rain into streams or bodies of water, this double use of the sewers was proper and economical. When, however, it was thought necessary to purify the sewage by treating it in various ways before permitting it to escape, it was found that such operations were rendered very difficult when the sewage, owing to the presence of rain water, varied greatly both in amount and character. It is a comparatively simple matter to design works to purify a regular quantity of (say) one million gallons of sewage of nearly uniform quality. It would be almost impossible to design works to handle and purify sewage liable to vary in quantity from one to fifty million gallons, and also to vary greatly in its chemical constituents. For this reason the proposition is generally accepted at present, that wherever sewage must be purified by any mode of treatment, it should be kept separate from the rainfall and conveyed in sewers which are used for no other purpose. In such cases, when it is also necessary to remove the

* Third Rept., p. 55.

rainfall by means of sewers, a distinct system of such structures, devoted to that purpose only, must be built. Such a double system of sewerage has both advantages and disadvantages. The sewers for sewage only can be very small, and will cost only about two-fifths as much as do those designed for carrying rain, or say $6,000 to $8,000 per mile. In some places, where the removal of rain is not a pressing necessity, and the cost of a large system of sewers would preclude its construction, small sewers for removing sewage proper can sometimes be built for a sum within the means of the town. When the system for removing rain must be co-extensive with that for removing the sewage, the cost of the double system will be about two-fifths greater than that of a single one. Usually, however, the rain water system need not be so extensive as the other, and the rain can be discharged at less distant outlets into brooks traversing the town, where it would not do to put sewage. The first portion of a rainfall, which washes yards and streets, becomes very dirty ; but the filth contained by it is not considered so dangerous as ordinary sewage, nor, coming as it does only occasionally, is it so liable to cause nuisances. Notwithstanding any disadvantages, the necessity for keeping the sewage by itself, whenever it is to be treated in any way, is so apparent that it may be laid down as a rule that it should be done where practicable.

The foregoing extract is of considerable interest by reason of embodying the views of Mr. Clarke, after he had been confronted, in his investigations for the Drainage Commission, with the various serious problems of sewage purification existing in the region which he specially studied.

In relation to the impossibility of treating the whole flow of combined systems at times of heavy rainfall, see Chapter VII., on Quantity of Sewage and Variation in Rate of Flow.

The Average Composition of American Sewage.

In American cities using from 60 to 100 U. S. gallons of water per capita per day, the sewage is naturally more dilute than in foreign cities where 30 to 50 U. S. gallons per capita is more nearly the daily allowance. As appositely remarked by Mr. Mills in the Special Report of the Massachusetts State Board of Health, we may say that the

Table No. 32.—Average Composition of the Sewage experimented upon at Lawrence for Four Years.

(Parts per 100,000.)

Year.	Free ammonia.	Albuminoid ammonia.			Chlorine.	Oxygen consumed.	Bacteria per cubic centimetre.
		Total.	Soluble.	Insoluble.			
1888..............	1.5528	.6878	.1611	.5267	5.19	....	1,000,000
1889..............	1.8439	.5540	.2909	.2631	4.92	...	708.000
1890..............	1.8200	.6862	.3805	.3057	5.45	3.25	1,085,000
1891..............	2.2196	.7295	.3446	.3849	7.37	3.64	693,000
Average—4 yrs.*	1,8591	.6644	.2943	.3701	5.73	3.44	871,009

* As may be expected in any growing town which has not yet attained approximately fixed conditions, the strength of the sewage is slowly increasing, the average total nitrogen for 1891 being about 25 per cent. greater than for 1888.

sewage of an average American town will contain, when stronger than ordinary, say 998 parts of water, 1 part of mineral matter, and 1 part of organic matter. The mineral matter is not generally harmful, and the object of sewage purification can be stated as chiefly to get rid of the one-thousandth part of organic matter.

The composition of the sewage of American towns may be taken as averaging fairly with the results in Table No. 32, in which is given the average composition of the sewage received at the experiment station of the Massachusetts State Board of Health at Lawrence for four years. The table also shows the relations of the soluble albuminoid ammonia to the insoluble.

The Average Composition of English Sewage.

Table No. 33 gives the average composition of the sewage of a large number of English towns, as taken from the Report of the Rivers Pollution Commission. This table, while containing the averages of the most complete series of analyses of English town sewage that has yet been made, is unfortunately not entirely comparable with the previous table on account of the use of a different system of chemical analysis. If, however, we bear in mind (1) that free ammonia and ammonia, albuminoid ammonia, and organic nitrogen refer to the same things and (2) that the organic nitrogen is usually at least double the albuminoid ammonia, we are able to make comparisons which are close enough for ordinary purposes.*

Table No. 33.—Average Composition of Sewage of English Towns.†

(Parts per 100,000.)

Classes of towns.	Total solids in solution.	Organic carbon.	Organic nitrogen.	Ammonia.	Total combined nitrogen.	Chlorine.	Suspended matters.		
							Mineral.	Organic.	Total.
Midden towns	82.4	4.181	1.975	5.435	6.451	11.54	17.81	21.30	39.11
Water-closet towns...........	72.2	4.696	2.205	6.703	7.728	10.66	24.18	20.51	44.69

† 1st Rep. Riv. Pol. Com., pp. 28, 29.

Relation of American to English Sewage.

Comparing the averages of Tables 32 and 33, with this understanding, it becomes apparent that the ordinary sewage of English towns is

* This is intended as a general statement only. It is derived from the results of a number of comparative analyses of natural waters in which the albuminoid ammonia was determined by the Wanklyn process and the organic nitrogen by the Kjeldahl method, as given in paper On the Determination of the Organic Nitrogen in Natural Waters by the Kjeldahl Method, by Thomas M. Drown, M.D., and Henry Martin, S.B., Technology Quarterly, February, 1889. No comparisons were made with the combustion process of Frankland and Armstrong.

considerably more concentrated than that of American towns. This point, let us say, is a very important one to bear in mind in the application of English data to American conditions. The Massachusetts experiments have indicated that there is a relation between the purifying capacity of different filtering materials and the amount of impurity to be removed from samples of sewage of varying strength. This point is strongly brought out by the several series of experiments. From all of which it follows that with high grade intermittent filters, prepared in accordance with the indications of the Massachusetts experiments, we may expect to filter larger volumes of average American dilute sewage per unit of area than has usually been found expedient in English practice. The use, therefore, of English intermittent filtration data, without reference to either the quality of the filtering medium or the material filtered, will be likely to lead to erroneous conclusions.

The Composition of London Sewage.

If the comparison is in relation to the average sewage of London, somewhat different results appear. We find, indeed, that at present the London sewage does not differ greatly in composition from that of American towns. This conclusion is derived from Table No. 33A following, in which are given the means of a large number of analyses of London sewage, as made by W. J. Dibdin in 1883, and published in detail in the Report of the Royal Commission on Metropolitan Sewage Discharge:

Character of Drainage from Street Surfaces.

In regard to the drainage from street surfaces, the following analyses of the liquid flowing from two different classes of pavements, situated in the centre of the city of London, may be taken as showing the amount of pollution which such drainage will acquire in streets with large traffic: *

(In parts per 100,000.)

Composition.		Drainage from wood pavement.	Drainage from Macadam pavement.
Appearance		Dark color	Slate color
Odor		Strong urine	Urine
Chlorine		54.0	24.4
Free ammonia		6.89	3.54
Albuminoid ammonia		4.25	2.47
Oxygen absorbed by matters in solution in 15 minutes		0.68	0.38
Oxygen absorbed by matters in solution in 4 hours.		4.95	2.81
Suspended matter	Mineral	952.00	2020.60
	Loss on ignition	83.40	77.70
Dissolved solids	Mineral	462.10	178.60
	Loss on ignition	117.10	38.60

* From paper, Sewage Treatment and Sewage Disposal, by W. Santo Crimp, Eng. and Bld. Rec. vol. xxvii., p. 237 (Feb. 18, 1893).

TABLE No. 33A—MEANS OF ANALYSES OF LONDON SEWAGE MADE BY W. J. DIBDIN IN 1883.

(Parts per 100,000.)

	Number of samples in series.	Dissolved solids.			Ammonia.		Chlorine.	Suspended matter.		
		Total.	Mineral.	Organic.	Free.	Albuminoid.		Total.	Mineral.	Organic.
Samples from southern outfall	109	88.3	60.9	27.4	4.16	.523	18.0	37.5	16.7	20.7
Samples from northern outfall	72	79.4	51.6	27.9	5.05	.584	12.4	41.6	19.5	22.0
Average from both outfalls	181	83.9	56.2	27.7	4.60	.553	15.2	39.6	18.1	21.4
Percentage composition	......	100.0	67.0	33.0	......	......	......	100.0	46.0	54.0

It will be noticed that the drainage from wood pavement is considerably more polluted than that from the Macadam, but whether this is due in any degree to differences in the pavements themselves or entirely to variations in traffic is not stated.*

THE DATA OF HUMAN EXCREMENTS.

Tables Nos. 34, 35, and 36 furnish important data in regard to the amount of the solid and liquid excrements from a mixed population, together with the proportion of organic nitrogen and phosphates in the same.†

Excrements, however, do not comprise, as we have already seen, more than one-half of the total pollution in ordinary sewage; but even with this understanding, the variation in quality which results

TABLE No. 34.—WEIGHT IN POUNDS OF THE SOLID AND LIQUID EXCREMENTS OF A MIXED POPULATION OF 100,000 PERSONS FOR A YEAR.

Population by sex and age.	Fæces.			Urine.		
	Total.	Organic nitrogen.	Phosphates.	Total.	Organic nitrogen.	Phosphates.
37,610 men	4,521,664	52,416	98.672	45,217,782	452,144	183,456
34,630 women	1,237,040	28,000	30,038	37,458,512	297,136	151,648
14,060 boys	1,239,504	20,496	18,122	6,423,670	53.872	24,304
13,700 girls	274,736	6,270	4,032	5,041,344	40,320	19,152
Totals	7,272,944	107,182	150,864	94,141,308	843,472	378,560

* For discussion of the effect of different kinds of pavements upon the quality of the water draining off, together with the effect of much or little traffic on streets, see Report of General Board of Health on Metropolitan Water Supply, Appendix 3, p. 140. Professor Way, who made the series of analyses there discussed, has also given some of them in his paper On the Use of Town Sewage as Manure, in Jour. Roy. Ag. Soc., vol. xv, pp. 149–150.

† 1st Rept. of Riv. Pol. Com., p. 27. From the researches of Wolff and Lehmann.

TABLE No. 35. — WEIGHT IN GRAINS OF THE SOLID AND LIQUID EXCREMENTS PER PERSON PER DAY, AND THE ORGANIC NITROGEN AND PHOSPHATES CONTAINED THEREIN.

Sex and age.	Fæces.			Urine.		
	Total.	Organic nitrogen.	Phosphates.	Total.	Organic nitrogen.	Phosphates.
Men	2,315	27	50	23,148	231	94
Women	694	16	17	20,833	166	85
Boys	1,698	29	25	8,796	73	33
Girls	386	9	6	6,944	57	27
Means	1,273	20	25	14,930	132	60

TABLE No. 36.—WEIGHT IN POUNDS OF THE SOLID AND LIQUID EXCREMENTS PER PERSON PER YEAR.

Sex and age.	Fæces.			Urine.		
	Total.	Organic nitrogen.	Phosphates.	Total.	Organic nitrogen.	Phosphates.
Men	120.45	1.39	2.62	1,204.5	12.04	5.28
Women	36.08	0.80	0.86	1,083.9	8.61	4.38
Boys	88.33	1.51	1.29	457.7	3.79	1.73
Girls	20.07	0.46	0.29	361.3	2.95	1.40
Means	66.23	1.04	1.26	777.68	6.85	3.20

from differences in the amount of water supply becomes very apparent, especially when we study the question with Tables 34 to 36 before us.

In Tables Nos. 35 and 36 we have given the quantity of excrements per day and per year from average single persons, and also from 100,000 persons of an average urban population; and while we have already expressed the opinion in Chapter IV. that the theoretical values of the manurial constituents of sewage cannot be realized in practice, we nevertheless deem it desirable, for the completeness of the subject, to give a short discussion of fertilizers from the more recent agricultural point of view.

The three elements in manures of the greatest value to plant life are nitrogen, phosphoric acid, and potash. Nitrogen and phosphoric acid occur abundantly in human excrements, while potash occurs in somewhat smaller quantity. The following from Wolff, as given by Professor Storer,* shows the percentage composition of the leading contituents of human excrements.

* Agriculture, vol. ii., p. 70.

TABLE No. 36A.—AVERAGE COMPOSITION OF HUMAN EXCREMENTS.

(Per cent.)

Kind.	Water.	Organic matter.	Nitrogen.	Phosphoric acid.	Potash.	Lime.	Magnesia.
Fresh human fæces	77.2	19.8	1.00	1.10	0.25	0.62	0.36
Fresh human urine	96.3	2.4	0.6	0.17	0.20	0.02	0.02
Mixture of the two	93.5	5.1	0.7	0.26	0.21	0.09	0.06

In estimating the value of human excrements for manure it must be further remembered that night-soil, as ordinarily procurable, is not nearly so valuable as fresh excrements, because of the fermentations and leachings to which it is usually subject. The following tabulation, also from Storer (*loc. cit.*), gives the average composition of night-soil as taken from vaults, and presumably not subject other than as stated to leaching, dilution, etc.

TABLE No. 36B.—ANALYSES OF NIGHT-SOIL FROM VAULTS.

(Per cent.)

Locality.	Water.	Organic matter.	Nitrogen.	Phosphoric acid.	Potash.	Lime.	Magnesia.
Quesnoy, near Lille (?) (Girardin)*	98.04	2.66	0.92	0.33	0.21	......	......
" from large factory*	99.65	0.05	0.18	0.03	0.02	......	......
Lille, from a dwelling-house*	99.86	0.54	0.67	0.10	0.15	......	......
Paris, L'Hote†	99.12	1.28	0.44	0.14	......	0.16	......
Munich, mostly liquid	99.51	2.01	0.18	0.26	......	......	......
" thick liquid	90.52	7.35	0.69	0.52	......	......	......
Karlsruhe, large public vault (Nessler)	96.00	3.00	0.40	0.12	0.17	......	......
Cassel, public vault (Nessler)	......	......	0.90	......	......	......	......
Stuttgart, public vault (Wolff)	96.00	1.51	0.43	0.17	0.20	......	......
Groningen, average, mostly liquid (Fleischer)	97.10	......	0.29	0.01	0.36	......	......
Bremen, average, solid and liquid (Fleischer)	31.70	......	0.53	0.51	0.26	2.71	......
Average composition of night-soil from cities, mostly liquid (Wolff)	95.50	3.00	0.35	0.28	0.20	0.10	0.06

* The first specimen was undiluted and contained 0.76 per cent. of ammonia; the second, which was much diluted with water, contained only 0.21 per cent. of ammonia; the third, which was diluted with from twelve to fifteen per cent. of water, contained 0.57 per cent. of ammonia; all of these contained traces of nitrates.

† This specimen contained 0.52 per cent. of ammonia. The average of twelve different samples was 0.37 per cent. of nitrogen, the amount having ranged from 0.25 to 0.62 per cent.

Lawes and Gilbert give the following as the amounts of different substances in the solid and liquid excrements of an adult male in a year:

Dry substance—fæces, 23.75 pounds; urine, 34.5 pounds; total, 58.5 pounds.

Mineral matters—fæces, 2.5 pounds; urine, 12 pounds; total, 14.5 pounds.

Carbon—fæces, 10.0 pounds; urine, 12 pounds; total, 22 pounds.

Nitrogen—fæces, 1.2 pound ; urine, 10.8 pounds ; total, 12 pounds.

Phosphoric acid—fæces, 0.7 pound ; urine, 1.93 pound ; total, 2.63 pounds.

According to Wolff, the amount of potash from the excrements of an adult male per year is :

Fæces, 0.24 pound ; urine, 2.01 pounds ; total, 2.25 pounds.

In order to illustrate the relative manurial value of the excrements of different domestic animals in comparison with human, we have prepared Table No. 36C, the data for which are mostly derived from the researches of Wolff.

TABLE NO. 36C.—COMPARISON OF MANURIAL CONSTITUENTS OF THE EXCREMENTS OF DOMESTIC ANIMALS AND HUMAN BEINGS.

(Pounds per net ton.)

Annual.	Serial number.	Fresh fæces.			Fresh urine.		
		Nitrogen.	Phosphoric acid.	Potash.	Nitrogen.	Phosphoric acid.	Potash.
Horse	1	8.8	7.0	7.0	31.0	.....	30.0
Cow	2	5.8	3.4	2.0	11.6	.....	9.8
Sheep	3	11.0	6.2	3.0	39.0	0.2	45.2
Swine	4	12.0	8.2	5.2	8.6	1.4	16.6
Means of 1, 2, 3, and 4	5	9.4	6.2	4.3	22.5	0.4	25.4
Human being	6	20.0	22.0	5.0	12.0	3.4	4.0
Ratio of (5) to (6)	......	2.02	3.55	1.16	0.53	8.50	0.16

In sewage nitrogen is usually present, either as carbonate of ammonia and in other ammoniacal salts, or as organic nitrogen in combination with the organic matter. Phosphoric acid is present chiefly as either insoluble phosphates of lime and magnesia, or as soluble phosphates of soda and ammonia, the latter being the more important in an agricultural point of view. The soluble potash of sewage is mostly derived from excrements, while the insoluble balance chiefly results from the grinding up of granite pavements, the wash therefrom passing into the sewers.

According to Hoffmann and Witt in their report to the Commissioners of the Metropolitan Drainage, the manurial constituents in an imperial gallon of the average London sewage of their day were as follows:

Nitrogen, grains per gallon 6.76
Phosphoric acid, grains per gallon 1.85
Potash, " " " 1.03

A net ton of sewage of this average composition would contain:

Nitrogen .... 0.19 pound.
Phosphoric acid .... 0.053 "
Potash .... 0.029 "

With nitrogen at 17¢ per pound, phosphoric acid at 7¢, and potash at 5¢, the theoretical value of the fertilizing ingredients of such a sewage would be per net ton, 3.85 cents. If, however, we take into account the various losses of the nitrogen, which is the most valuable element, and the expense of distribution, we reduce the value, even when applied to the best advantage, to not more than from 1 to 2 cents per net ton. When flooded upon land at all times, whether required or not, the value as a fertilizer may quickly become *nil.**

* Many of the cognate questions in regard to the use and utilization of human excrements are of the greatest interest, and the reader who cares to pursue the subject farther should consult Storer's Agriculture, vol. ii., p. 71, and following. Also p. 292 and following of the same volume.

The following papers, to be found in Jour. of the Roy. Ag. Soc. of Eng., will be of interest to any person wishing to study the question of the use of fertilizers in all its bearings. They are a few only of the more important which have been published by the Roy. Ag. Soc. since the beginning of its journal in 1840:

(1) On the Composition and Money Value of the Different Varieties of Guano. By J. Thomas Way, consulting chemist to the Roy. Ag. Soc. Vol. x., pp. 196–230.

(2) On the Power of Soils to Absorb Manure. By J. Thomas Way. Vol. xi., pp. 313-379. Also in vol. xiii., pp. 123-143.

(3) On Agricultural Chemistry—Especially in Relation to the Mineral Theory of Baron Liebig. By J. B. Lawes and Dr. J. H. Gilbert. Vol. xii., pp. 1-40.

(4) On Superphosphate of Lime: its composition and the methods of making and using it. By J. Thomas Way. Vol. xii., pp. 204-236.

(5) On the Use of Town Sewage as Manure. By J. Thomas Way. Vol. xv., pp. 135-137.

(6) The Atmosphere as a Source of Nitrogen to Plants; being an account of recent researches on this subject. By J. Thomas Way. Vol. xvi., pp. 249-267.

(7) On the Composition of the Waters of Land Drainage and of Rain. By J. Thomas Way. Vol. xvii., pp. 123-162.

(8) On the Composition of Farmyard Manure, and the Changes which it undergoes on Keeping under Different Circumstances. By Dr. Augustus Voelcker, Professor Chemistry in the Roy. Ag. Col., Cirencester. Vol. xvii., pp. 191-260.

(9) On Farmyard Manure, the Drainings of Dungheaps, and the Absorbing Properties of Soils. By Dr. Augustus Voelcker. Vol. xviii., pp. 111-150.

(10) On Liquid Manure. By Dr. Augustus Voelcker. Vol. xix., pp. 519-552.

(11) On the Changes which Liquid Manure undergoes in Contact with different Soils of known composition. By Dr. Augustus Voelcker. Vol. xx., pp. 134-157.

(12) Farmyard Manure. By J. B. Lawes. Vol. xxiii., pp. 45-48.

(13) On the Commercial Value of Artificial Manures. By Dr. Augustus Voelcker. Vol. xxiii., pp. 277-286.

(14) On the Utilization of Town Sewage. By J. B. Lawes. Vol. xxiv., pp. 65-90.

(15) Earth *versus* Water for the Removal and Utilzation of Excrementitious Matters. By the Rev. Henry Moule. Vol. xxiv., pp. 111-123.

(16) The Money Value of Night-soil and other Manures. By P. H. Frere. Vol. xxiv., pp. 124-131.

(17) On the Composition and Practical Value of Several Samples of Native Guano prepared by the A B C Sewage Process of the Native Guano Company. By Dr. Augustus Voelcker. Sec. Ser., vol. vi., pp. 415-424.

(18) On the Composition and Agricultural Value of Earth-closet Manure. By. Dr. Augustus Voelcker. Sec. Ser., vol. viii., pp. 185-203.

(19) On the Composition of Waters of Land Drainage. By. Dr. Augustus Voelcker. Sec. Ser., vol. x., pp. 132-165.

(20) On the Valuation of Unexhausted Manures. By J. B. Lawes. Sec. Ser., vol. xi., pp. 1-38.

(21) On the Amount and Composition of the Drainage Waters Collected at Rothamsted. By J.

EXPLANATIONS CONCERNING THE ANALYSIS OF FERTILIZERS AND THE VALUATION OF THEIR ACTIVE INGREDIENTS.*

NITROGEN is the most rare, and commercially the most valuable, fertilizing element.

Free nitrogen is indeed universally abundant in the common air, but in this form its effects in nourishing vegetation are as yet obscure.

Organic nitrogen is the nitrogen of animal and vegetable matters, which is chemically united to carbon, hydrogen, and oxygen. Some forms of organic nitrogen, as those of blood, flesh, and seeds, are highly active as fertilizers; others, as found in leather and peat, are comparatively slow in their effect on vegetation, unless these matters are chemically disintegrated.

Ammonia (NH_3) and nitric acid (N_2O_5) are results of the decay of organic nitrogen in the soil and manure heap, and contain nitrogen in its most active forms. They occur in commerce—the former in sulphate of ammonia, the latter in nitrate of soda; 17 parts of ammonia or 66 parts of pure sulphate of ammonia, contain 14 parts of nitrogen; 85 parts of pure nitrate of soda also contain 14 parts of nitrogen.

PHOSPHORUS is, next to nitrogen, the most costly ingredient of fertilizers, in which it always exists in the form of phosphates, usually those of calcium, iron, and aluminum, or in case of some "super-phosphates," in the form of free phosphoric acid.

Soluble phosphoric acid implies phosphoric acid or phosphates that are freely soluble in water. It is the characteristic ingredient of super-phosphates, in which it is produced by acting on "insoluble" or "reverted" phosphates, with diluted sulphuric acid (oil of vitriol). Once well incorporated with the soil, it gradually becomes reverted phosphoric acid.

Reverted (reduced or precipitated) phosphoric acid means strictly, phosphoric acid that was once easily soluble in water, but from chemical change has become insoluble in that liquid. In present usage the term signifies the phosphoric acid (of various phosphates) that is freely taken up by a strong solution of ammonium citrate, which is therefore used in analysis to determine its quantity. "Reverted phosphoric acid" implies phosphates that are readily assimilated by crops.

Recent investigation tends to show that soluble and reverted phosphoric acid are on the whole about equally valuable as plant food, and

B. Lawes, J. H. Gilbert, and Robert Warington. Sec. Ser., vol. xvii., Part I., pp. 241-279; Part II., pp. 311-350; vol. xviii., Part I., pp. 1-71.

(22) On the Valuation of Unexhausted Manures. By Sir J. B. Lawes and J. H. Gilbert. Sec. Ser., vol. xxi., pp. 590-611.

* From the An. Rept. of the Conn. Ag. Ex. Sta. for 1890, pp. 17-18.

of nearly equal commercial value. In some cases, indeed, the soluble gives better results on crops, in others the reverted is superior. In most instances there is probably little to choose between them.

Insoluble phosphoric acid implies various phosphates not soluble in water or ammonium citrate. In some cases the phosphoric acid is too insoluble to be readily available as plant food. This is especially true of the crystallized green Canada apatite. Bone-black, bone-ash, South Carolina rock and Navassa phosphate, when in coarse powder, are commonly of little repute as fertilizers, though good results are occasionally reported from their use. When very finely pulverized ("floats") they more often act well, especially in connection with abundance of decaying vegetable matters. The phosphate of calcium in raw bones is nearly insoluble, because of the animal matter of the bones, which envelops it; but when the latter decays in the soil, the phosphate remains in essentially the "reverted" form. The phosphoric acid of "Thomas-Slag" and of "Grand Cayman's Phosphate" is freely taken up by crops.

Phosphoric acid . . . is reckoned as "anhydrous phosphoric acid" (P_2O_5), also termed among chemists, phosphoric anhydride, phosphoric oxide, and phosphorus pentoxide.

Potassium is the constituent of fertilizers which ranks third in costliness. In plants, soils, and fertilizers it exists in the form of various salts, such as chloride (muriate), sulphate, carbonate, nitrate, silicate, etc. Potassium itself is scarcely known except as a chemical curiosity.

Potash signifies the substance known in chemistry as potassium oxide (K_2O), which is reckoned as the valuable fertilizing ingredient of "potashes" and "potash salts." In these it should be freely soluble in water and is most costly in the form of sulphate, and cheapest in the form of muriate (potassium chloride).

The valuation of a fertilizer . . . consists in calculating the retail trade-value or cash cost (in raw material of good quality) of an amount of nitrogen, phosphoric acid, and potash equal to that contained in one ton of the fertilizer.

Plaster, lime, stable manure, and nearly all of the less expensive fertilizers have variable prices, which bear no close relation to their chemical composition; but guanos, superphosphates, and similar articles, for which \$30 to \$50 per ton are paid, depend chiefly for their trade-value on the three substances, nitrogen, phosphoric acid, and potash, which are comparatively costly and steady in price. The trade-value per pound of these ingredients is reckoned from the current market prices of the standard articles which furnish them to commerce.

The consumer, in estimating the reasonable price to pay for high-

grade fertilizers, should add to the trade-value of the above named ingredients a suitable margin for the expenses of manufacture, etc., and for the convenience or other advantage incidental to their use.

Theoretical Values.

In order to indicate the *theoretical* value of the nitrogen, phosphates and potash of sewage, the following statement of trade values of the fertilizing ingredients in raw materials and chemicals, as used by the New York State Agricultural Experiment Station during 1892 and 1893, is included. It is stated that the valuations obtained by the use of these figures will agree fairly well with the average retail price of standard raw materials.*

	1892. Cts. per pound.	1893. Cts. per pound.
Nitrogen in ammonia salts	17½	17
" in nitrates	15	15½
Organic nitrogen in dry and fine ground fish, meat, and blood, and in high-grade mixed fertilizers	16	17½
Organic nitrogen in cotton-seed meal and castor-pomace	15	16½
" " in fine ground bone and tankage	15	15
" " in fine ground medium bone and tankage	12	12
" " in medium bone and tankage	9½	9
" " in coarse bone and tankage	7½	7
" " in hair, horn shavings, and coarse fish scraps	7	7
Phosphoric acid, soluble in water	7½	6½
" " soluble in ammonium citrate	7½	6
" " in fine bone and tankage	7	6
" " in fine medium bone and tankage	5½	5
" " in medium bone and tankage	4½	4
" " in coarse bone and tankage	3	3
" " in fine ground fish, cotton-seed meal, castor-pomace, and wood ashes	5	5
Phosphoric acid in fine ground rock phosphate	2	2
Potash as high-grade sulphate, in forms free from muriates (chlorides), in ashes, etc	5½	5½
Potash in kainit	4½	4½
" in muriate	4½	4½
Organic nitrogen in mixed fertilizers	17	17½
Insoluble phosphoric acid in mixed fertilizers	2	2

VALUATION OF FERTILIZING INGREDIENTS IN FOODS.

Organic nitrogen	——	17½
Phosphoric acid	——	5
Potash	——	5½

The authors are not to be understood as in any way implying that the theoretical values indicated by the foregoing table can be realized in sewage utilization in practice.

*Bul. No. 52—New Series (March, 1893), Analysis of Commercial Fertilizers. N. Y. Ag. Exp. Sta., Geneva, N. Y., Peter Collier, Director.

The Fixed Data of Sewage Disposal.

Tables 34 to 36 inclusive are given as about the only approximately fixed data in sewage disposal; all the other elements being subject to relatively greater variations than occur in the average amount of excrements of a fixed population. Amount of water used per capita, whether the sewerage system is separate or combined, amount and quality of the manufacturing wastes, all these will enter into the problem in any given case.

The Mechanical Analysis of Soils.

We come now to the consideration of an entirely different class of data, which have recently been found of fundamental importance in sewage disposal, namely, that derived from a mechanical analysis of the material to be used either for broad irrigation or intermittent filtration. A thorough knowledge of the mechanical properties of soils will, with other data derived from the Lawrence experiments, enable one to determine beforehand approximately the amount of purification which can be attained with any given soil.

There are a number of methods by which the mechanical ingredients of a soil may be separated from each other, but the most important ones, aside from or in connection with the use of sieves, are the Hilgard's Elutriator, and Osburn's Beaker method. The use of these two methods is only possible, however, when one has at hand a fairly well equipped physical laboratory, and in a practical way much may be learned by the mere use of a series of sieves of different degrees of fineness.

Classification of Soil Particles.

The following table gives the classes into which the materials composing soils may be separated with reference to the diameters of the particles:

			mm.		mm.
Grits of fine gravel	with	diameter	of 2.0	down	to 1.0
Coarse sand	"	"	1.0	"	0.5
Medium sand	"	"	0.5	"	0.25
Fine sand	"	"	0.25	"	0.10
Very fine sand or dust	"	"	0.10	"	0.05
Silt	"	"	0.05	"	0.01
Fine silt	"	"	0.01	"	0.005
Clay	"	"	0.005	"	0.0001

Quality of Material Required for Intermittent Filtration.

In sewage disposal by intermittent filtration, it is necessary for successful purification to use material the particles of which are large

enough to allow the organic matters in suspension in the sewage to pass into the interstices, where they are resolved into primary elements through the action of nitrification. As we shall see in the discussion of the results of the experiments at Lawrence, in Chapter XIV., on Intermittent Filtration, very fine soils are less useful for sewage purification than coarse, clean sands. In order to illustrate the differences

TABLE No. 37.—MECHANICAL ANALYSES OF TYPICAL SOILS FROM THE SOUTH CAROLINA AGRICULTURAL EXPERIMENT STATION FARMS.

(Per cent.)

Ingredients.	Diameter of grains.		Spartanburg farm.		Columbia farm.		Darlington farm.	
			Upland.		Sandy.		Sandy.	
	Millimetres.	Inches.	Soil.	Red subsoil.	Soil.	Subsoil.	Soil.	Subsoil.
Grits	Above 1 mm.	Above 0.04	11.300	5.293	1.276	1.430	2.361	2.565
Coarse sand	1.0 to 0.50	0.04 to 0.02	6.545	4.236	43.390	36.486	35.308	27.330
Medium sand	0.50 to 0.25	0.02 to 0.01	5.541	2.742	23.626	25.156	14.222	10.190
Fine sand	0.25 to 0.10	0.01 to 0.004	10.293	6.123	11.820	14.537	14.211	11.501
Very fine sand	0.10 to 0.05	0.004 to 0.002	37.709	23.672	7.875	8.708	22.981	19.605
Silt	0.05 to 0.01	0.002 to 0.0004	21.363	45.021	9.740	12.473	10.220	28.180
Clay	Less than 0.01	Less than 0.0004	6.956	11.804	1.733	1.077	.281	.166
Totals			99.707	98.891	99.460	99.867	99.584	99.537
Per cent. of porosity			71.388	42.066	87.987	86.317	89.683	71.191

in mechanical constituents which exist in natural soils, reference may be made to Tables 37 and 38, in which are included the mechanical analyses of a number of soils from the South Carolina Experiment Station Farms, as given in the Second Annual Report of the South Carolina Experiment Stations.

TABLE No. 38.—APPROXIMATE NUMBER OF PARTICLES IN ONE GRAM OF SOIL FROM THE FARMS OF THE SOUTH CAROLINA AGRICULTURAL EXPERIMENT STATIONS (SEE TABLE 37); TOGETHER WITH THE DIAMETER OF THE AVERAGE SIZED PARTICLE IN MILLIMETRES.

Ingredients.	Average diameter.	Spartanburg.		Columbia.		Darlington.	
		Soil.	Red subsoil.	Soil.	Subsoil.	Soil.	Subsoil.
	Mm.						
Grits	1.5	24	10	3	3	5	5
Coarse sand	0.75	112	73	747	624	606	469
Medium sand	0.375	759	378	8,602	3,363	1,951	1,399
Fine sand	0.15	22,040	13,210	25,370	31,070	30,470	24,670
Very fine sand	0.075	646,000	408,800	135,300	149,000	385,200	336,400
Silt	0.03	5,717,000	12,150,000	2,613,000	3,333,000	2,677,000	7,557,000
Clay	0.005	402,200,000	687,900,000	100,680,000	60,900,000	16,270,000	9,615,000
Total number of particles.		408,585,935	700,472,471	103,463,022	64,417,060	19,365,232	17,534,943
Diameter of average sized particle		0.01209	0.01009	0.01911	0.0224	0.03337	0.04384

TABLE No. 39. — SURFACE AREA OF PARTICLES IN ONE GRAM OF SOIL FROM THE FARMS OF THE SOUTH CAROLINA AGRICULTURAL EXPERIMENT STATIONS (SEE TABLES 37 AND 38). IN SQUARE CENTIMETRES.

Ingredients.	Average diameter in millimetres.	Spartanburg.		Columbia.		Darlington.	
		Soil.	Red subsoil.	Soil.	Subsoil.	Soil.	Subsoil.
Grits	1.5	1.7	0.8	0.2	0.2	0.4	0.3
Coarse sand	0.75	2.0	1.2	13.2	11.0	10.7	8.2
Medium sand	0.375	3.3	1.6	38.2	18.7	8.6	6.1
Fine sand	0.15	1.96	9.3	17.9	21.9	21.5	17.4
Very fine sand	0.075	114 2	72.2	23.9	26.3	68.0	59.4
Silt	0.03	161.7	343.6	73.9	94.2	75.6	213.7
Clay	0.005	316.2	540.3	79.1	47.8	12.7	7.5
Total surface		618.7	969.0	246.2	220.1	197.5	312.6

In Table 39 is given the surface area in one gram of soil from the same localities.*

Thus far, general studies of the mechanical constituents of soils have been carried to a somewhat greater degree of perfection at the South

TABLE No. 40.— PER CENT. OF EMPTY SPACE IN A NUMBER OF SOILS IN COMPARISON WITH AVERAGE SIZE OF PARTICLES, APPROXIMATE NUMBER OF PARTICLES, AND SURFACE AREA PER GRAM.

Locality.	Diameter of averaged sized particles, in mm.	Approximate number of particles in 1 gram.	Per cent. of empty space.	Surface area per gram, in square centimetres.
Illinois, "prairie soil"	0.0067	2,372,994,000	55.2	2279.1
Sea Island, "cotton soil"	0.0257	42,355,000	46.4	186.1
East Windsor, Conn., "clay soil"	0.0087	1,101,430,000	48.3	1406.8
Granville Co., N. Car., "tobacco soil"	0.0111	507,103,000	32.0	619.9
East Windsor, Conn., "blowing sand"	0 0124	367,634,000	44.7	399.6
Columbia, S. C., farm "soil" †	0.01911	103,463,000	40.7	246.2
Columbia, S. C., farm "subsoil" †	0.0224	64,417,000	42.4	220.1
Darlington, S. C., farm "soil" †	0.03337	19,365,000	34.6	197.5
Darlington, S. C., farm "subsoil" †	0 04384	17,534,000	39.9	312.6
"Coarse river sand"	0.208	7,980	38.4	10.9
"Coarse river sand"	0.833	1.240	41.0	27.2
Maryland, "pine barrens"	....	1,692,000.000	40.0	495.8
Maryland, "truck"	....	6,868.000,000	45.0	1669.6‡
Maryland, "tobacco"	....	8,258,000.000	50.0	2102.2‡
Maryland, "wheat"	....	10,358,000,000	55.0	2602.1‡
Maryland, "river terrace"	....	11,684,000,000	55.0	2924.4‡
Maryland, "limestone (grass land)"	....	24,653,000,000	....	5573.7‡

† For detail of analyses of these samples see Tables 37, 38, and 39.
‡ The number of square feet of surface per cubic foot for these soils, with large particle areas, are:

	Square feet.		Square feet.
Pine barrens	23,940	Wheat	94,540
Truck	74,130	River terrace	106,200
Tobacco	84,850	Limestone	202,600

Carolina and Maryland Agricultural Stations than at any other place in this country, the work at both of these stations having been di-

* For formulæ for computing the diameter of the average sized particles, number of particles in a gram, surface area, etc., see 2d An. Report S. Car. Ag. Ex. Stations, Appendix, pp. 95–96.

rected by Professor Milton Whitney, whose researches in this direction are of great theoretical value. But for practical value in connection with sewage purification, the studies of the mechanical composition of filtering materials made at the Lawrence Experiment Station, and outlined, with deductions, in the Report of the Massachusetts State Board of Health for 1891, are first in rank. In order to further illustrate the differences in soils which exist at various localities, we have included Table No. 40, compiled from the Second Annual Report of the South Carolina and the Fourth Annual Report of the Maryland Agricultural Experiment Stations.

In Table No. 41 are given the mechanical analyses of the material from a number of the experimental tanks at Lawrence, as detailed in the Massachusetts report mentioned just above.

TABLE No. 41.—MECHANICAL COMPOSITION OF THE MATERIALS USED IN A NUMBER OF THE EXPERIMENTAL FILTER TANKS AT THE LAWRENCE EXPERIMENT STATION.*

Diameter in millimetres.	Per cent.							
	No. 5.	No. 4.	No. 2.	No. 9.	No. 6.	No. 1.	No. 5A.	No. 16.
Finer than 12.6	99	—	—	—	83	100	100	98
" " 6.2	96	—	—	—	73	97	95	27
" " 2.2	92	—	—	—	57	85	31	0
" " .98	89	—	—	100	32	53	4	—
" " .46	80	—	100	91	13	7	2	—
" " .24	67	100	90	26	7	1.5	1.5	—
" " .12	51	85	43	3	4	0	1.0	—
" " .06	33	35	10	0	2	—	0.5	—
" " .03	16	10	2	—	0.5	—	0	—
" " .01 (Organic)	6	1	0	—	0	—	—	—

* These figures are based on the weight of the sand particles finer than the sizes given in the first column.

The studies at Lawrence are so clearly and concisely set forth by Mr. Allen Hazen † that we cannot do better than to give them here as follows:

MECHANICAL COMPOSITION OF MATERIALS USED AT LAWRENCE.

In making a mechanical analysis the sand is first sifted through a series of sieves, each, in a general way, twice as fine as the one next coarser. The sand passing the finest sieve is divided into several portions by beaker elutriation. Each portion is weighed, and the range in the sizes of its particles is determined by micrometer measurement in the case of the smaller particles, but the diameters of the larger particles can be more conveniently and accurately calculated from their weight. The diameters of all particles are taken at, as nearly as possible, the diameter of a sphere of equal volume. Of course the sand grains are irregular. With the Lawrence sands the average lengths of their axes, selecting the longest and taking the other two at right angles to it, are to each other as 4 : 3 : 2, and the mean diameter, taken as the cube root of the product of the three axes, 2.88. The longest diameter thus averages to be nearly 40 per cent. longer than the mean diameter, while the middle diameter, which is the width as seen by a microscope, is an approximation to the mean diameter.

† Chemist in charge of the station. 23d An. Rept. Mass. St. Bd. Hlth., pp. 428 *et seq.*

The analyses of some of the materials which have been most carefully studied in their relations to sewage purification are shown in the preceding table (No. 41). The figures given show the per cent. by weight of the different materials having smaller diameters than the size given in the first column. These results have been revised by improved methods of analysis, so that in some cases the following figures differ slightly from those given in the report upon the Purification of Sewage and Water.

For study and comparison the results have been plotted, and are shown on the accompanying diagram (Fig. 7), the height of curve at any point showing the per cent. of material finer than the size indicated at the bottom of the diagram. The lines representing the diameters are spaced according to the logarithms of the diameters of the particles, as in this way materials of corresponding uniformity in the range of sizes of their particles give equally steep curves, regardless of the absolute sizes of the particles, thus greatly facilitating a comparison of different materials. This scale also shows adequately every grade of material from 0.01 to above 10 millimetres in a small space, and without unduly extending any portion of the scale. It is assumed for the purpose of plotting that the particles of organic matter (determined by the loss due to heating that portion of the material finer than the 140 mesh sieve to a dull red heat) are less than 0.01 millimetres in diameter

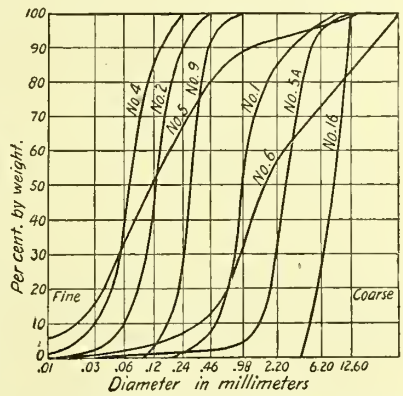


FIG. 7.—MECHANICAL COMPOSITION OF SAND USED FOR FILTRATION AT THE LAWRENCE EXPERIMENT STATION.

These materials may be said to include the whole range of sands available for sewage purification. Anything as fine as No. 5* is too fine for advantageous use, while, at the other end, it would hardly be safe to depend upon a gravel coarser than No. 16 with a filtering stratum not over five or six feet in thickness.

With the mixed materials, Nos. 5 and 6, the smaller particles fill the spaces between the larger, and these finer portions determine the capillary attraction of the filter, its resistance to the passage of sewage, and, in fact, its action in every way. The appearance of No. 6 is coarser than No. 1, and the average size of its particles is greater, but its finest portion determines its character as a filter, so that it is practically finer than No. 1. It has been found as the result of a careful study that the

TABLE NO. 41A—SIZE AND UNIFORMITY COEFFICIENT OF FILTERING MATERIALS USED AT LAWRENCE.

Number of filter.	Ten per cent. of material finer than (millimetres).	Uniformity co-efficient.
No. 5	0.02	9.0
4	0.03	2.3
2	0.06	2.3
9	0.17	2.0
6	0.35	7.8
1	0.48	2.4
5A	1.40	2.4
16	5.00	1.8

points where the curves in the diagram cut the 10 per cent. line give the best idea of the total effect of the various materials. By measurements of the diagram we

* For convenience the different materials are numbered to correspond with the filter tanks in which they were first used.

find that with the various materials 10 per cent. by weight of the particles are smaller than the sizes given in the following table. This gives as good an idea of the relative effect of sizes of the materials as can be condensed into a single figure for each.

To obtain a definite basis of comparison of the uniformities of the sizes of the grains of different materials, the ratios between the diameters of the particles at the 10 per cent. line, as given above, and the diameters at the 60 per cent. line are given in the table (No. 41A,) under the heading "Uniformity Coefficient." If all the grains of a sand were absolutely of the same size, the coefficient would be 1; with a majority of our comparatively even-grained sands the coefficient ranges from 2 to 3; with No. 6 and No. 5, the figures are 8 and 9 respectively, and some extremely uneven sands have coefficients as high as 20 or 30, but our data in regard to the action of such materials is as yet very limited.

Relation Between Quality of Filtering Material and Quantity of Applied Sewage.

The actual quantities of sewage which have been found to be the best adapted to seven of the Lawrence experimental filters under the most favorable circumstances, together with the size and depth of the filtering materials, size of dose and frequency of application are given in Table 41B.

Table No. 41B.—Quantity of Sewage Applied to Different Filtering Materials at Lawrence.

Material.	Diameter of grain, mm. 10 per cent. finer than—	Depth of material (ft.).	Size of dose.		Number of doses in one week.	Average amount applied daily, gals. per acre.
			Gallons per acre.	Per cent. of volume of filter.		
No. 16	5.00	5	2,800	0.17	500	200,000
1	.48	5	40,000	2.45	18	103,000
6	.35	4	70,000	5.37	6	60,000
9	.17	5	120,000	7.36	6	103,000
2	.06	5	140,000	8.60	3	60,000
4	.03	5	80,000	4.91	3	34,000
5	.02	5	0	–	–	0

Additional data under this head appears in Chapter XIV., on Intermittent Filtration. Chapter XVII., On the Temperature of Air and Natural Soils, also presents further data applying to broad irrigation and intermittent filtration.

CHAPTER IX.

DISCHARGE INTO TIDAL OR OTHER LARGE BODIES OF WATER.

UNDER this head little needs to be said in addition to the preliminary discussion in Chapter I., which has already indicated that the present work is not specially concerned with this particular form of disposal. As useful examples the sewerage of two large cities may be referred to.

EARLY AMERICAN SEWERAGE SYSTEMS.

The sewerage system of the city of Chicago, designed by E. S. Chesbrough, C.E., in 1855, has usually been considered a model on which other towns could safely build. At that time the idea that the prevalence of typhoid fever and many other infectious diseases was directly related to the presence of sewage in drinking-water had hardly been broached in this country, and even in England, where rational ideas of sanitation developed at a relatively early date, the great bulk of the sanitary literature which has since enriched the English language had at that time hardly more than began to come into being. The discussions of the fifteen or twenty years immediately preceding that period had, however, awakened sanitary authorities to the necessity of getting rid of waste products in some more effectual way than by turning into cesspools or by merely throwing into streets. The English sewerage systems of the period from 1850 to 1860 were chiefly constructed, therefore, with reference to getting sewage first of all out of the houses and towns, and undoubtedly, even though the outfall emptied in many cases into the nearest small watercourse, the improvement in public health was nevertheless as a whole markedly apparent.

SEWERAGE AT CHICAGO.

Thanks to the foresight of Mr. Chesbrough, Chicago has had, ever since the initiation of permanent sewer construction in 1855, a predesigned system which has been systematically carried out from year to year. Before designing the same, Mr. Chesbrough visited England in order to study the state of the art of sewerage there, and we may conclude, inasmuch as there were at that time absolutely no models on which to build in this country, that the Chicago sewerage system was

made a fair epitome of current foreign practice with such modification as the ablest municipal engineer of the day considered desirable in order to fit it to the conditions of a rapidly developing American metropolis. As preliminary, then, to a short description of the Chicago outfall sewers, we may properly examine, though briefly, the antecedent circumstances which led to considerable activity in systematic sewer building in England, in the fifth decade of the present century.

Condition of English Towns Fifty Years Ago.

The beginning of modern sanitary science in England is indicated by the first report of the Health of Towns Commission in 1844. The rapid and alarming increase in the death-rate in many of the English towns had been, it is true, the subject of partial investigation by parliamentary committees previous to that time; but the earlier reports, while frequently voluminous, add almost nothing to the stock of knowledge of the evil investigated; and it was only on the publication of the Health of Towns Commission's Report that exact information as to the cause of the increase became available. The Commission's first report, together with the second and third of the series, revealed a condition of affairs in many of the English towns of that day which has thus far been without parallel in this country. Even New Orleans at its worst must have been a cleanly city in comparison with what existed in many of the English towns in 1844.* For instance, in Liverpool it was found that a cellar population amounting to more than 20,000 persons was absolutely without any place of deposit for its refuse matter, while in houses inhabited by the working-classes a large proportion were in a similar predicament.† The reports abound in similar statements, many of them in reference to whole streets in populous districts, and in some cases nearly whole towns, where the public streets were the only places of deposit for the most

* See vol. xix. of Tenth Census of U. S., Social Statistics of Cities, Pt. II., pp. 264–267, where may be found, in the article on New Orleans, a graphic presentation of the ravages of the several cholera epidemics at New Orleans. Chicago, however, was itself sufficiently unhealthy for the year immediately preceding the beginning of sewer construction in accordance with the general plan of Mr. Chesbrough. Indeed, it was chiefly a succession of epidemics of cholera and dysentery for several years which led, in February, 1855, to the passage of an act by the Illinois Legislature creating the Chicago Board of Sewer Commissioners. The construction of sewers began in 1856. It should be stated in this connection that the first public water supply was introduced in 1840 by a company when the population was small; that more extensive works were built by the city in 1852–54, just at the close of the first period named directly below. In 1867 the first water intake tunnel was built beneath the lake, greatly improving the supply, and in 1874 a second intake tunnel was added. All these facts should be considered in this connection, and especially in connection with the note to the following table. From 1845 to 1856 the mean annual death-rate had been 39.91 per 1,000, while from 1856 to 1870 it was only 23.97. The following table shows the

† 1st Rept. Health of T. Com., vol. i., p. 128.

offensive waste products of the human economy; and into these all such were indiscriminately pitched, even from second-story windows or balconies, as the case might be.* As recently as 1861 we find it stated with regard to one place, that even in the centre of the town no accommodation of any kind is provided, and hence the adult male population defecate habitually in the gardens or in the road,† and so on *ad nauseam.* When we consider that the Health of Towns Commission's Reports relate to a period only 50 years past, and the conditions described existed in several places less than 25 years ago, and it is only within 35 or 40 years that any material improvement has been effected in some of the worst localities, we may appreciate the enterprise of the people of Chicago in sending their chief engineer abroad in 1855 in order that he might profit, in designing the Chicago system, to the fullest extent, by whatever new or useful had been developed under the active agitation of sanitary questions which then prevailed in England.‡

Results of the Early Sewerage Systems.

As the result of turning the house sewage of a large number of towns, as well as the manufacturing wastes of many rapidly developing manufacturing centres in various parts of the county into the streams, a nuisance of a new character was soon created which was quite as serious as the one which the construction of sewers had been more or

number of feet of sewers built annually, the population, mortality, and the death-rate per 1,000 for the series of years from 1856, when the first sewers were constructed, to 1870:

Year.	Feet of sewer built.	Population.	Deaths.	Death-rate per 1.000.
1856	31,794	84,113	2,086	24.80
1857	25,681	93,000	2,414	25.66
1858	101,879	84,000	2,255	26.84
1859	55,208	96,000	2,008	21.36
1860	69,024	109,260	2,264	20.70
1861	2,826	120.000	2,279	18.99
1862	15,685	137,030	2,835	20.69
1863	39,605	150,000	3,875	25.83
1864	25,021	161,288	4,448	27.57
1865	29,948	178,492	4,029	22.57
1866	48,127	200,418	6,524	32.22
1867	89,661	225,000	4,648	21.17
1868	47,841	252,000	5,984	23.74
1869	139,705	280,000	6,488	23.16
1870	78,166	299,227	7,343	24.53

From 1870 to 1879, inclusive, the death-rate was 21.15. (From "Sanitary Problems of Chicago, Past and Present." By John H. Rouch, M.D. Reprint from Sec. An. Rept. of the Ill. St. Bd. of Health, p. 10.)

* In verification of these statements see 1st Rept. Health of T. Com., *loc. cit.;* also 2d Rept. Health of T. Com., vol. i., p. 370; vol. ii., p. 84. Also see Repts. Med. Officer Priv. Council.

† 4th Rept. Health Officer Priv. Coun., 1861.

‡ For more complete résumé of the sanitary condition of the English towns 50 years ago, see Corfield's Treatment and Utilization of Sewage, 3rd Ed., Chapters i. to iii., inclusive.

less successful in relieving. Hence, sewage disposal, purification, or utilization, became a pressing question in the fifth decade of the century. A clear idea of the various views prevailing at that time may be obtained from either the Preliminary Report of the Sewage of Towns Commission or the Report of Henry Austin, On the Means of Deodorizing and Utilizing the Sewage of Towns.*

Mr. Chesbrough's Chicago Report.

The state of sewage disposal in England at about the time of Mr. Chesbrough's study of the English methods has been briefly presented in order to saliently illustrate the fact that, while no adequate conception of the evils resulting from mixing house sewage with drinking-water existed at that time, even with people who had made sanitation a specialty, nevertheless Mr. Chesbrough must have returned from Europe very thoroughly permeated with the prevailing views as to the necessity of some form of sewage purification; and it is accordingly interesting to notice that the matter of ultimate disposal occupies an important place in his report of 1855. By reason of being, so far as the authors can learn, the first American report in which sewage disposal other than by discharge into the nearest water-course is touched at all, we derive an additional incentive for inquiring how this question happened to receive extended consideration in connection with the sewerage plans of an American city at that relatively early day. The preceding historical paragraphs answer the question thus raised, and without dwelling further on this part of the question, we may proceed to consider the sewerage system actually designed.

Mr. Chesbrough's report begins, after a short introductory paragraph, by asking the question, What shall the sewage of the city be drained into? The answer is that four principal plans have been proposed, namely:

(1) Into the river and its branches directly, and thence into the lake.

(2) Directly into the lake.

(3) Into artificial reservoirs, to be thence pumped up and used as manure.

(4) Into the river, and thence by the proposed steamboat canal into the Illinois river.

* The Sewage of Towns Commission, the commission of which bears date January 5, 1857, were directed under its terms "to inquire into the best mode of distributing the sewage of towns and applying it to beneficial and profitable uses." Their first report was issued in 1858. The Report of Henry Austin, C.E., was presented to the President of the General Board of Health in 1857. In these two reports may be found a fair summation of the various methods of sewage disposal of that day, the Report of the Sewage of Towns Commission treating the question mostly from the point of view of utilization by agriculture, while the Report of Mr. Austin presents the side of the chemical purificationists of 35 years ago.

In order, according to the report, to take advantage of the natural facilities of the site at a minimum of expense, the first plan as given above was adopted; that is, the sewage of the city was from economic considerations discharged by way of the river into Lake Michigan.

The objections to the third plan as stated in the report were:

(1) The great uncertainty about there being a demand for the sewage after it is pumped up, sufficient to pay for distributing it.

(2) The great evil that would necessarily result from a failure of the reservoirs through insufficiency of capacity, especially if the system of sewers leading to them should have their outlets too low to empty into the lake or river. If the reservoirs should be made so large as to place them beyond all doubt of having sufficient capacity, they would be very expensive, both on account of the labor and material required in their construction and the ground they would occupy.

(3) There would be danger to the health of the city during the prevalence of winds from the quarter in which the sewage might be used as a manure, especially if only a few miles distant and spread over a wide surface.

Mr. Chesbrough's third objection to the use of sewage has been found by the more extended experience of later years to be mostly without foundation for fairly well-managed sewage farms.

Mr. Chesbrough remarks that should the time ever arrive when the value of the sewage would be so great as to permit of saving it for this purpose, the sewers as designed would still serve their purpose as conduits for surface water, while a system of small pipes to take house sewage, only, could be laid down at a minimum expense.

With regard to the fourth plan of draining into the proposed steamboat canal, and thence into the Illinois river, Mr. Chesbrough also remarks that this is too remote a contingency to be relied upon for present purposes. We shall see, however, in Part II., that a partial application of this method by utilization of the Illinois and Michigan canal has been in use more or less continually since 1865.*

The Chicago River.

The Chicago river, before its enlargement through the city for purposes of navigation, was a small stream of sluggish flow with a total drainage area of perhaps 300 square miles. It divides in the central part of the city, at a point about a mile from the lake, into two branches, the North branch and the South branch, the North branch being about 30 miles in length, and the South branch about 5 miles. Both run nearly parallel to the lake shore, and only a short

* For complete text of Mr. Chesbrough's Chicago Report, see Eng. News, vol. ii. (1875), pp. 42, 55, and 79.

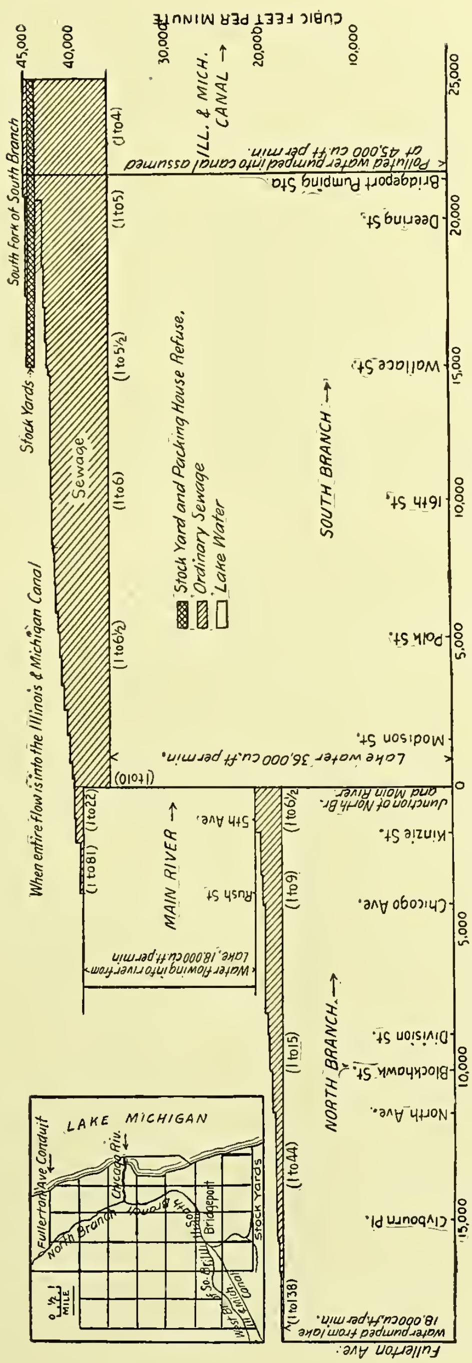
distance from it. The enlarged river now comprises the inner harbor, which had, according to data collected in 1887,* a total dock frontage, including slips, of 20.7 miles, and an area of 406.0 acres. The inner harbor is estimated to contain over 60,000,000 cubic feet of water. In dry weather it receives only a small amount of water from the restricted drainage area of the river from which it is formed, and what it does receive is contaminated before reaching Chicago. Into such a broad area of already contaminated water is poured daily, except as noted below, the sewage of a large portion of the city, amounting in 1890 to at least 22,000,000 cubic feet daily. Hence the daily inflow of sewage is about one-third of the total contents of the harbor. This extreme pollution of the river-harbor was first relieved in 1865 by forcing a large amount of water from the river into the Illinois and Michigan canal, thereby causing a flow of water from Lake Michigan through the city into the canal, and so on to the Des Plaines river at Joliet. This, however, only partially relieved the South branch. For the relief of the North branch, a tunnel 12 feet in diameter was built beneath Fullerton avenue and extended into Lake Michigan. This tunnel was first operated in 1880. Two screws capable of forcing 15,000,000 cubic feet per day at ordinary speeds furnish a motive power by which a current may be sent either from the river into the lake, or by reversal of the machinery from the lake into the river, as may be found most desirable at different stages of the two bodies of water.

Fig. 8, from the Report of the Chicago Drainage Commission, shows the relative proportions of sewage and lake water in the Chicago river and its branches.

For the more complete relief of the South branch, pumping machinery of a nominal capacity of 60,000 cubic feet per minute was provided at Bridgeport, the point where the Illinois and Michigan canal connects with the Chicago river, in 1883. A brief description of these works, together with one of the Fullerton Avenue conduit, is given in Part II. In 1893 improvements were in progress designed to increase the capacity of the Bridgeport works to 100,000 cubic feet per minute, or over 1,000,000,000 gallons per 24 hours, against 6 ft. head.

The continual rapid increase of the population of Chicago has, however, produced such further fouling of the river as to lead to a revival in the last few years of the project of a large navigable canal from Lake Michigan to the Illinois river drainage at Joliet, through which enough water can be sent each day to not only entirely relieve the river of its present visible pollution, but which will, it is hoped by the projectors, also so far dilute its waters as to render the Chicago sewage in effect harmless to the Illinois river communities who derive

* The Lakes and Gulf Waterway as related to the Chicago Sanitary Problem. By L. E. Cooley, C.E., p. 23.



(Numbers in brackets represent proportions of sewage and lake water at points indicated.)

FIG. 8—PROPORTIONS OF SEWAGE AND LAKE WATER IN THE CHICAGO RIVER AND ITS BRANCHES.

their water supplies from that river. A complete description of the project in all its bearings would extend beyond the limits of this chapter, where the only object is to call attention to some of the difficulties which have attended sewage disposal at Chicago; but it should be added that work is now in progress, under the direction of the Trustees of the Sanitary District of Chicago, on a drainage canal designed to have a capacity of at least 300,000 cubic feet per minute. In rock cut the capacity of the canal will be 600,000 cubic feet. Brief consideration of the relations of the discharge of a considerable portion of the sewage of the city in such manner as to finally find its way into Lake Michigan, from which the water supply of the city is also drawn, may be properly made. In favor of the present project of discharging to the Des Plaines river it is urged that in prehistoric times there existed a channel to the south through which at any rate a portion of the waters of Lake Michigan originally discharged to the Illinois and finally to the Mississippi river.

The Chicago Water Supply.

The present water supply of the city is derived from Lake Michigan through tunnels and intake pipes. The first two tunnels were constructed in 1864–67 and 1872–74, respectively. They are parallel, 46 feet apart, and are driven through clay about 30 feet below the lake bottom to a distance of two miles from the shore, where they terminate in timber cribs, inclosing shafts. The first tunnel is 5 feet wide by 5 feet 2 inches high, and lined with substantial brick masonry; the second is of the same material and 7 feet in diameter; it extends under the city for four miles, passing under the river and South branch to the West side pumping station. A third tunnel was constructed in 1887–92, which extends into the lake a distance of four miles; it also extends under the city a distance of 1½ miles to connect with the new Central and Fourteenth street pumping stations, and also with the old tunnel. The lake section was started with a diameter of 8 feet, but the unfavorable material encountered necessitated two 6-foot tunnels for a good part of the distance. A tunnel 6 feet in diameter and 1¼ miles long also forms a part of the Chicago water-works. It was built jointly by Hyde Park and Lake, which towns were annexed to Chicago in 1889. The former town of Lake View, also annexed to Chicago in 1889, was until quite recently supplied through several iron intakes, but a tunnel 6,500 feet long now takes the place of these intakes; this tunnel is being extended to a length of 10,000 feet. On March 1, 1893, the total daily capacity of the several tunnels was officially reported as being 504,000,000 gallons and the total pumping capacity of the city water-

works as 356,000,000 gallons. The average daily water pumpage for the year 1892 was 195,000,000 gallons.*

Contamination of the Chicago Water Supply.

At various times the evidence of sewage contamination about the water supply intakes has been unmistakable, and it is generally conceded that the water supply is ordinarily more or less polluted by the sewage which finds its way into the lake. The increase in the death-rate from typhoid fever has been considerable in the last few years (see Table No. 3), a fact which, with our present views as to the causation of typhoid, can hardly be satisfactorily explained except by assuming an increasing contamination of the water supply; we may, therefore take Chicago as an illustration of the force of the statement of the opening chapter, that sewage ought not to be discharged into any body of water also used as the source of a public water supply at any point within the influence of the sewage.

The Boston Main Drainage.

The most elaborate system of disposal by special appliances for discharge into tide-water yet carried out in this country is that of the city of Boston, the Main Drainage Works of which, as completed in 1884 may be justly regarded a model work of the kind; before describing the Main Drainage we will briefly discuss the antecedent conditions which rendered the works a necessity.†

Early Sewers of Boston.

The first sewers of Boston were undoubtedly constructed in the latter part of the 17th century, as we find that at the town meeting of September 22, 1701, it was ordered "that no person shall thenceforth dig up the ground in any of the streets, lanes or highways in this town, for the laying or repairing of any drain, without the leave or approbation of two or more of the selectmen." These early sewers were probably built on the co-operative plan. Several neighbors, needing drainage, joined together and constructed a sewer by the shortest line to tide-water. The expense was divided between the interested parties who owned the drain in common. Any party outside of the original owners who desired to connect was obliged to pay for the privilege

* For the latest detailed information regarding the Chicago water supply and sewerage systems and the quality of the water, see the 17-page account in the London Lancet, Apr. 8, 1893, or an extended abstract in Eng. News, vol. xxix., pp. 438-9 (May 11, 1893).

† The following account of the sewers of Boston and the Main Drainage Works is abstracted from Eliot C. Clarke's Main Drainage Works of the City of Boston.

whatever they saw fit to charge. The expense of repairs was divided between the parties using the drain when the repairs were made.

The Massachusetts Sewer Act of 1709.

This method, while answering the purposes for the construction of the first drains, was found unsatisfactory when extended, and in 1709 the Colonial Legislature passed an act regulating the construction of drains and sewers. This act of 1709 is the foundation of the present system of sewer assessments in most of the New England as well as some of the other States, and its provisions may be properly cited at some length. It is entitled: An Act passed by the Great and General Court or Assembly of Her Majesty's Province of the Massachusetts Bay, for Regulating of Drains and Common Shores,* for Preventing Inconveniences and Damages by frequent breaking up of Highways . . . and of differences arising among Partners in such Drains or Common Shores about their Proportion of the Charge for Making and Repairing the same.

The act provides (1) a penalty for breaking up the ground in any highway within any town for laying, repairing, or amending any common shore, without the approbation of the selectmen; (2) that all such structures, for the draining of cellars, shall be substantially done with brick or stock;† (3) that it shall be lawful for any inhabitant of any town to lay a common shore or main drain for the benefit of themselves and others who shall think fit to join therein, and every person who shall afterward enter his or her particular drain into such main drain, or by more remote means receives benefit thereby, for the drainage of their cellars or lands, shall be obliged to pay unto the owner or owners a proportionate part of the charge of making or repairing the same, or that part of it below where their particular drain enters. Disputes were settled by references to the selectmen, who decided the amount each person should pay. An appeal from the selectmen's decision could be taken to the courts.

The sewers of Boston were built, repaired, and owned under the provisions of this act until 1823, when a new charter was obtained. One of the first acts of the new city government was to assume control of all existing sewers and of the building and care of new ones.

In regard to the sewers built by private enterprise between the years 1709 and 1823, little can be said in their praise, although the greater part of Boston of that day was thus sewered by private enterprise. The contents of privies were excluded, but they received the wastes from pumps and kitchen sinks, and also rain-water from roofs and yards. That much refuse got into them is proved by their frequently

* Sewers. † Stone.

filling up. This difficulty led to disputes about payments for repairs, so that in 1763 the act of 1709 was amended in such manner as to provide for assessment of cost of repairs on all persons benefited.

In 1824 Mayor Josiah Quincy, in referring to the old sewers, said:

> No system could be more inconvenient to the public or embarrassing to private persons. The streets were opened with little care, the drains built according to the opinion of private interest or economy, and constant, interminable, vexatious occasions of dispute occurred between the owners of the drain and those who entered it, as to the degree of benefit and proportion of contribution.

Since 1823 the sewers have all been built by the city, with varying proportions of the expense, as before, charged to the estates benefited, but apportioned with reference to their assessed valuation. Previous to 1838, a small variable portion of the cost was generally assumed by the city in consideration of its use of the sewers for the removal of storm water from the streets; in that year the city decided to assume one-quarter of the gross cost.*

The Limits of Original Boston.

The original city of Boston, by reason of being a town on hills, with quick descent to the water in all directions, was comparatively easy to sewer, but the changes which have taken place through the reclaiming and filling of the tidal areas bordering the old limits have transformed it into a city presenting many obstacles to the construction of efficient sewerage.

This will be understood by examining Fig. 9, on which the shaded portion represents very nearly the area of the city in 1823. The unshaded portion consists entirely of reclaimed land, filled to such an extent that the streets of the reclaimed district are seldom over seven feet above mean high water. A large proportion of the house basements and cellars are lower than high water, and frequently but from five to seven feet above low-water mark, the mean rise and fall of the tide being ten feet. Most house drains are under the cellar floors, and fall in reaching the street sewers, while the latter, in their turn, fall towards their outlets, which are rarely much above low water. As a consequence the contents of the sewers were dammed back by the tide during the greater part of each twelve hours. Salt water was excluded from many of them by tide-gates, which closed as the sea rose, also at the same time shutting in the sewage, which accumulated, and, being without currents, deposits occurred.

At about the time of low water the tide-gates opened and the sewage escaped, to be met almost immediately by the incoming tide and

* Since the above was put in type the Report of the Superintendent of Streets of Boston for 1893 has come to hand, in which is a résumé of all the various forms of assessments, with a discussion of recent changes.

brought back by it to form deposits upon the flats and shores about the city. Stony brook, Back bay, and South bay are the localities where the greatest nuisances were created in this way.

The position of the principal original sewer outlets is indicated on Fig. 9, where are also shown the lines of the intercepting sewers which were finally designed as a remedy for the difficulty.

The Boston Sewerage Commission of 1875.

In March, 1875, a commission consisting of Messrs. E. S. Chesbrough, M. Am. Soc. C.E., Moses Lane, M. Am. Soc. C.E., and Chas. F. Folsom, M.D., were appointed by the mayor to report upon existing sewerage, and to present a plan for outlets and main lines of sewers for the future wants of the city. Their report contained a comprehensive and exhaustive statement of the defects in the existing system and of the causes which had led to it, and recommended a well considered plan for remedying the existing defects and providing for future needs.

The following extract from the report gives some of the more interesting points:

The point which *must* be attended to, if we would get increased comforts and luxuries in our houses, without doing so at cost of health and life, is to get our refuse out of the way, far beyond any possibility of harm, before it becomes dangerous from putrefaction. In the heat of summer this time should not exceed twelve hours. We fail to do this now in three ways:

(1) We cannot get our refuse always from our house-drains to our sewers, because the latter may not only be full themselves at high tide, but they may even force the sewage up our drains into our houses.

(2) We do not empty our sewers promptly, because the tide or tide-gates prevent it. In such case the sewage becomes stagnant, a precipitate falls to the bottom, which the slow and gradual emptying of the sewers, as the tide falls, does not produce scour enough to remove. This deposit remains with little change in some places for many months.

(3) With our refuse, which is of an especially foul character, once at the outlets of the sewers, it is again delayed, there to decompose and contaminate the air.

As a result of this failure to carry out the cardinal rule of sewerage, we are obliged to neglect the second rule, which is nearly as important, namely, ventilation of the sewers; for the gases are often so foul that we cannot allow them to escape without causing a nuisance; and we compromise the matter by closing all the vents that we can, with the certainty of poisoning the air of our houses.

In the opinion of the commission there are only two ways open to us. The first, raising more than one-half of the superficial area of the city proper (excluding suburbs), is entirely out of the question, from the enormous outlay of money which would be required—more than four times as much as would be needed for the plan which we propose, and which consists in intercepting sewers and pumping.

There are in use now in various parts of the world three methods of disposing of the sewage of large cities, where the water-carriage system is in use:

(1) Precipitation of the solid parts, with a view to utilizing them as manure, and to purifying the streams.

(2) Irrigation.

Neither of these processes has proved remunerative, and the former only *clarifies* the sewage *without purifying* it; but if the time comes when, by the advance in

FIG. 9.—MAP SHOWING THE ORIGINAL BOSTON, OLD SEWER OUTLETS, NEW INTERCEPTING SEWERS, AND THE OUTFALL SEWER TO MOON ISLAND.

our knowledge of agricultural chemistry, sewage can be profitably used as a fertilizer, or if it should now be deemed best to utilize it, in spite of a pecuniary loss, it is thought that the point to which we propose carrying it will be as suitable as any which can be found near enough to the city, and at the same time far enough away from it.

(3) The third way is that adopted the world over by large cities near deep water, and consists in carrying the sewage out so far that its point of discharge will be remote from dwellings, and beyond the possibility of doing harm. It is the plan which your Commission recommend for Boston.

Fig. 9 shows the main and intercepting sewers as finally worked out in detail for Boston proper and South Boston, in accordance with the recommendation of the commission. Their report also included a separate line of interception for East Boston and the territory to the North of the Charles river, which, however, was not adopted at that time.*

Description of the Boston Main Drainage.

A description of the improved system, as actually carried out, divides naturally into four parts:

(1) The intercepting and main sewers which carry the sewage by gravity to the pumping stations.

(2) The pumping station where the sewage is raised to a sufficient height to permit it to flow by gravity through a tunnel under Dorchester bay to Moon island.

(3) The deposit sewers leading from the pumping station to the tunnel shaft and the tunnel itself under the bay.

(4) The reservoir at Moon island in which the sewage is stored, and the appliances for discharging the same during ebb tide.

The plan included lines of intercepting sewers, by means of which nearly all the original outfalls were cut off and the sewage diverted to the pumping station at Old Harbor point, the most easterly portion of the calf pasture in Dorchester. The main sewer leading to this point is about 3.25 miles long. Beginning at the junction of Huntington avenue and Camden street, its inclination throughout its whole extent is 1 in 2,500. At the pumping station the water line of the invert is about 14 feet below mean low tide, where also the diameter is 10.5 feet, a dimension which holds until the point of junction of the South Boston intercepting sewers is reached in a distance of about a mile. Above the point where the South Boston intercepting sewers join the main sewer, the latter is reduced to nine feet in diameter, and continues of that size to Albany street where the intercepting sewer for the east

* The sewerage of this latter territory is now in process of construction under the Metropolitan Sewerage Commission. For accounts of the engineering features involved see (1) Mr. Clarke's Report to the Massachusetts Drainage Commission (1886); and (2) a Report of the State Board of Health upon the Sewerage of the Mystic and Charles River Valleys (1889).

side of old Boston joins. Beyond this the main sewer is again reduced in size to 8 feet 3 inches high, which dimension holds until the end of the main sewer is reached at Huntington avenue, where the intercepting sewer for the west side begins.

The first intercepting sewer from the pumping station is, as already stated, that for South Boston, which by its two branches is intended to encircle the peninsula on which South Boston is situated, and intercept the sewage which had been hitherto discharged at 19 outlets. At the point of junction the grade of this intercepting sewer is 1.5 feet higher than that of the main sewer, this rise in grade insuring (1) that the sewage in the former will not be dammed back, and (2) that the established rate of inclination of the surface in both sewers will be maintained at the time of maximum discharge. This intercepting sewer is six feet in diameter up to the point where it divides, with an inclination throughout the greater portion of 1 in 2,000. The diameters and sections of the two branches are varied to suit local conditions.

The second large intercepting sewer which enters the main sewer is that for the east side, connecting at East Chester park and Albany street. Stony brook intercepting sewer connects at Tremont street; and the intercepting sewer for the west side at Huntington avenue and Camden street. These intercepting sewers are generally laid at a grade of 1 in 2,000, though in a few places a somewhat more rapid gradient was used. The total length of intercepting sewers now in use is about 12.75 miles, making with the main sewer about 15 miles in all. The size of the intercepting sewers varies from about 5.5 to 6 feet in diameter, at their junctions, to 3 to 4 feet and smaller at the extreme ends, according to the needs of the different localities.

The flowing sewage, on its arrival at the pumping station, first passes through a filth-hoist, where all floating objects liable to interfere with the action of the pumps are intercepted and at stated intervals removed. The sewage then passes on to the pumps, by which it is lifted about 35 feet into the deposit sewers, which are nearly a quarter of a mile in length. These consist of two parallel conduits 8 feet wide and 16 feet deep; they are dammed at their lower ends to maintain a depth of 8 to 10 feet, in order that the flow through them may be very sluggish, so that suspended matter will be deposited before reaching the tunnel; they are provided with the necessary arrangements for draining and cleaning.

In Table No. 42 is given the amount of sewage passing through the deposit sewers in each month of the year 1887, and the amount of sludge removed from them in the same time, also by months.

From Table No. 42 we derive the fact that the deposited matter amounts to 0.31 cubic yard per 1,000,000 gallons of sewage passing through the sewers.

TABLE No. 42.

Month.	Amount of sewage pumped, gallons.	Amount of sludge removed, cubic yards.	Month.	Amount of sewage pumped, gallons.	Amount of sludge removed, cubic yards.
January, 1887	1,818,101,420	69.9	August, 1887	1,205,322,183	512.4
February	1,507,178,534	....*	September	1,073,328,655	672.6
March	1,638,591,404	139.7	October	1,157,233,278	605.3
April	1,512,945,916	482.9	November	1,114,037,646	523.0
May	1,122,655,791	368.2	December	1,353,478,600	601.6
June	1.218,930,586	505.3			
July	1,183,342,262	496.6	Totals	15,905,146,275	4977.5

* Nothing removed during this month.

At the farther end of the deposit sewers is a masonry chamber, built about the tunnel shaft and connecting with it. At this shaft chamber are two waste sewers through which, in case of emptying the tunnel for inspection, etc., the sewage can be temporarily discharged into Dorchester bay.

The shaft at the end of the deposit sewers is 149 feet deep. From its foot there are 6,088 feet of nearly horizontal tunnel leading to the east shaft, beyond which there are 923 feet of inclined tunnel leading to the end on Squantum neck. From Squantum to Moon island an embankment, one mile long, 20 to 30 feet high, 20 feet wide on top and 120 feet at its base, in which to construct the outfall sewer, was built. About 4,100 feet of the site of this embankment consisted of beds of mud from 10 to 40 feet deep. After the bank was completed, slight settlement occurring, it was deemed prudent to postpone building a masonry structure for some years, until the bank has assumed a condition of permanent stability. Hence a wooden flume was constructed, 200 feet to the south of the embankment, for temporary use. It consists of a wooden box six feet square, supported on bents of three piles each ten feet apart.

The reservoir, at present covering an area of about five acres, is so built that extension can be made readily at the south side, as required in the future. In this reservoir the sewage is received as it flows from the temporary flume just described, where it is retained until after the turn of the tide, when it is discharged by opening a series of gates which permit the whole contents of the reservoir to flow out in about 20 to 30 minutes. A description of how this is accomplished, with full details of other portions of the work, are given by Mr. Clarke, and the reader is referred to his book for a more extended account.

A view of the reservoir is shown by Fig. 10.

The velocity of the ebb tide from Moon island outward is about two miles an hour; on account of this velocity and the commanding posi-

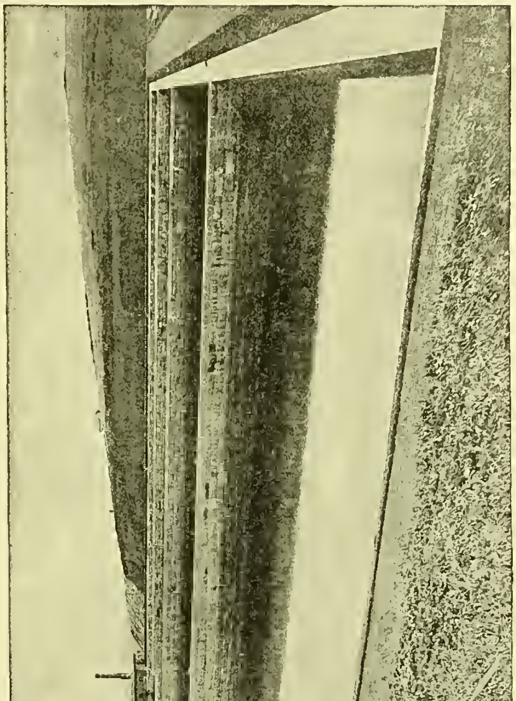


Fig. 10.—View of Moon Island Storage Reservoir, Boston Main Drainage.

tion of the island, it results that all visible traces of the sewage are so completely lost in the vast body of water in less than two miles flow as to be indistinguishable by chemical tests. The Boston Main Drainage Works therefore satisfy the conditions laid down in Chapter IV., on The Self-Purification of Running Streams and the Rational View in Relation to the Disposal of Sewage by Discharge into Tide-Water; indeed, these works may be considered a good illustration of the correct principle governing the discharge of sewage into tide-water.

CHAPTER X.

ON NITRIFICATION AND THE NITRIFYING ORGANISM.*

The Fundamental Principle of Nitrification.

The necessary essential for the resolution of organic matter into more primary forms of matter through the operation of nitrification is that the nitrifying organism shall be present in conjunction with an alkaline mineral base. The value of an alkaline base has been practically known for at least 2,000 years, as exemplied by the Greeks, the Gauls, and the Britons liming the land which they cultivated. Varro states that he saw laborers on the banks of the Rhine fertilizing their land with white marl.

Puvis, in his Treatise on Manures, mentions the excellent results in the Department du Nord, where the custom of using calcareous manures has been followed for centuries. Nevertheless the real action of the lime on the soil has only been recently understood, and we may profitably review a few of the more interesting investigations of nitrification which have been made in the last 150 years.

In 1749 Piertsch, in a short treatise addressed to the Academy of Sciences at Berlin, stated the circumstances which he considered most favorable to nitrification, as follows: (1) The presence of calcareous matter; (2) considerable porosity of the earth to offer a free passage to the air; (3) the putrefaction of animal or vegetable substances; (4) heat and humidity.

In 1778 Clouet and Lavoisier proved that the lime of Touraine and that of Saintonge nitrify very readily.

In 1782 Thouvenal, in an essay which gained a prize from the Paris Academy of Science, remarked that a basket of chalk placed over blood in a state of putrefaction produced a considerable quantity of saltpetre.

In 1784 Cavendish demonstrated that nitrification requires the contact of an alkaline solution.

In 1785 Rozier, in his "Course of Agriculture," said: "Stratifying the dunghill with lime decomposes the air contained in the manure and converts it into nitre, which gives to the soil an extraordinary fertility."

* The preliminary discussion of this chapter has been abstracted mostly from a paper on Nitrification of the Soil, by M. P. Bortier, Mem. Roy. Ag. Soc., in Jour. Roy. Ag. Soc. of Eng., vol. xxiii. (1862), pp. 354-357.

Subsequently a number of chemists demonstrated that the effect of atmospheric air acting upon a manure-heap is to nitrify it by degrees.

WARINGTON'S PAPER BEFORE THE SOCIETY OF ARTS IN 1882.

Coming down to more recent times, so far as the English literature of the subject is concerned, the most exhaustive papers explaining the conversion of ammonia and the nitrogen of organic substances into nitrates in the soil are those of Robert Warington. In his paper before the Society of Arts * in 1882 the theory of the purification of sewage is so clearly set forth that we may quote from it at length:

Dilute solutions of urine, or of ammonium salts, containing the essential constituents of plant food, undergo no nitrification, though freely exposed to the air, if only they have been previously boiled and the air supplied to them is filtered through cotton wool. If to such sterilized solutions a small particle of fresh soil is added, no action at first appears, but after a while nitrification sets in and the ammonia or urea is converted into a nitrate. For the productiou of nitric acid it is necessary that some base should be present with which the nitric acid may combine. The action proceeds best in the dark. When a solution has thus undergone nitrifacation, a drop of it suffices to induce nitrification in another solution, which, unless thus seeded, would have remained unchanged. Boiling the soil, or the solutiou that has nitrified, entirely destroys its power of causing nitrification. The presence of antiseptics also prevents nitrification. Lastly, nitrification is confined to the same range of temperature which limits other kinds of fermentation. The production of nitrates proceeds very slowly near the freezing-point, but increases in rapidity as the temperature rises, reaching its maximum of energy, according to Schlæsing and Muntz, at 37° C. (99° Fahr.). At higher temperatures the rate of nitrification rapidly diminishes; it almost ceases, according to the same observers, at 50° C. (122° Fahr.), and at 55° C. (131 Fahr.) no change occurs. It thus appears that nitrification can only be produced in the presence of some nitrified or nitrifying material, and the whole course of the action is limited to the conditions suitable to the activity of a living ferment. The French chemists claim to have isolated the ferment by systematic cultivation; it belongs to the family of bacteria.

The purifying action of soil on sewage is probably due to three distinct actions: 1. Simple filtration, or the separation of suspended matter. 2. The precipitation and retention by the soil of ammonia and various organic substances previously in solution. 3. The oxidation of ammonia and organic matter by the agency of living organisms. The last mode of action is undoubtedly the most important, as without oxidation the sewage matter must accumulate in the soil and the filter bed lose its efficacy. The filtering power of a soil will depend entirely upon its mechanical condition. The precipitating power of soil is, on the other hand, a chemical function, in which the hydrated ferric oxide and alumina and the silicates of soils probably play the principal part. The oxidizing power of a soil will depend partly on its mechanical, partly on its chemical, and partly on its biological condition. It was formerly supposed that the oxidizing power of a soil depended solely on its porosity, oxidation being assumed to occur by simple contact with air in the pores of the soil. We now know that a porous medium is by no means essential for nitrification; sewage may, indeed, be nitrified in a glass bottle, or when passing over polished pebbles. Though, however, porosity is by no means essential to the nitrifying power of a soil, it is undoubtedly a condition having a very favorable influence on the rapidity of the process; a porous soil of open texture will present an immense surface, covered with oxidizing organisms, and generally well supplied with the air requisite for the discharge of their functions. It is doubtless owing to this fact that nitrification takes place with so much greater rapidity in a soil

*Jour. Soc. Arts, April, 1882.

than in a liquid. The sewage will itself supply the substances required for the nourishment of the oxidizing organisms. One material essential to nitrification may, however, sometimes be deficient, namely, the base with which the nitric acid is to combine; without the presence of this salifiable base, nitrification will speedily come to a stand-still. In the case of towns supplied with hard water, the sewage may contain as much carbonate of calcium in solution as will suffice for its subsequent nitrification in the soil; but in case of towns supplied with very soft water, this can hardly be the case, and the presence of a considerable amount of lime in the soil itself will become essential for efficient nitrification. The organisms which effect the oxidation of organic matter are abundantly present in surface soils, but are probably absent, or nearly so, in subsoils; in surface soils they will probably be abundant in proportion to the richness of the soil in organic matter. Sewage also contains the organisms necessary for its own destruction, and under favorable conditions these may be so cultivated as to effect the purpose. A filtering medium of pure sand and limestone, treated intermittently with sewage, will, after a time, display considerable purifying powers, the surfaces becoming covered with oxidizing organisms derived from the sewage. No such medium will, however, equal in effect a porous soil rich in organic life. It will be gathered from the observations now made that it would be possible to construct a filter-bed having a greater oxidizing power than would be possessed by an ordinary soil and subsoil. Such a bed would be made by laying over a system of drain-pipes a few feet of soil obtained from the surface (first 6 inches) of a good field, the soil being selected as one porous, and containing a considerable amount both of carbonate of calcium and organic matter. A filter-bed thus prepared would be far more porous than a natural soil and subsoil, and would possess active oxidizing functions throughout its whole depth. The oxidizing power of soil must always be considerably greater in summer than in winter. The favorable influence of the warmer seasons of the year is apparently seen in several of Frankland's experiments on the intermittent filtration of sewage; the same influence of temperature will be plainly shown in some of the Rothamsted results. When we turn, however, to the analyses of the effluent water from irrigated land, the fact is not always manifest. We must recollect, however, that a considerable part of the nitrates produced in summer will be assimilated by the growing crops, and will therefore not appear in the drainage water. The oxidizing power of a soil may also be in excess of the work provided for it, so that even with a low temperature the usual amount of purification may be attained. A low temperature will also affect only the oxidizing functions of the soil, its power of precipitating and retaining sewage matter will remain unchanged. One more point may be worth notice. We have already referred to the fact that nitrification, like all other kinds of fermentation, ceases in the presence of antiseptics; the refuse of chemical works may thus sometimes prove a great hindrance to the purification of sewage by soil.

Warington's Paper of 1884.

In 1884 Mr. Warington read a paper before the British Association for the Advancement of Science * in which he somewhat extended the views of nitrification which he had expressed in the paper before the Society of Arts in 1882. The following extracts from the paper in 1884 may be made:

The evidence for the ferment theory of nitrification is now very complete. Nitrification in soils and waters is found to be strictly limited to the range of temperature within which the vital activity of living ferments is confined. . . . Nitrification is also dependent upon the presence of plant food suitable for organisms of low character. Recent experiments at Rothamsted show that in the absence of phosphates no nitrification will occur. Further proof of the ferment theory is afforded

* Report of 54th Meeting Brit. Assn. for the Adv. Sci., Montreal, 1884.

by the fact that antiseptics are fatal to nitrification. In the presence of a small quantity of chloroform, carbon bisulphide, salicylic acid, and apparently also phenol, nitrification entirely ceases. The action of heat is also equally confirmatory. Raising sewage to the boiling-point entirely prevents it undergoing nitrification. The heating of soil to the same temperature effectually destroys its nitrifying power. Finally, nitrification can be started in boiling sewage, or in other sterilized liquid of suitable composition, by the addition of a few particles of fresh surface soil, or a few drops of a solution which has already nitrified; though without such addition these liquids may be freely exposed to filtered air without nitrification taking place. . . .

Small quantities of soil were taken, at depths varying from two inches to eight feet, from freshly-cut surfaces on the sides of pits sunk in the clay soil at Rothamsted. The soil removed was at once transferred to a sterilized solution of diluted urine, which was afterward examined from time to time to ascertain if nitrification took place. From the results it would appear that in a clay soil the nitrifying organism is confined to about 18 inches of the top soil; it is most abundant in the first 6 inches. It is quite possible, however, that in the channels caused by worms or by the roots of plants, the organism may occur at greater depths. In a sandy soil we should expect to find the organism at a lower level than in clay, but of this we have as yet no direct evidence.

The later investigations show the presence of the nitrifying organism at as great depths in porous soils as four feet.

The Massachusetts Investigations.

The work of the Massachusetts State Board of Health on nitrification, as published in Part II. of the Special Report, furnishes us with a large amount of recent information, and we may conclude the theoretical part of this chapter by quoting some of the more important portions of the discussion: *

The oxidation of the nitrogen of ammonia, and its ultimate conversion into nitric acid, is called nitrification. This change is especially active in soils near the surface, where nitrates are formed abundantly from percolating waters which contain much nitrogenous matter.

This phase of nitrification, the formation of nitrates in porous soil, has been attentively studied. But less attention has been given to the process of nitrification as it goes on in surface waters, such as streams and ponds; and it is to this side of the question, namely, nitrification as it occurs in natural waters, that our study has been chiefly directed.

Some eighty samples of water, selected from two hundred and forty coming each month to the laboratory of the State Board of Health, were examined at intervals of from two to seven days for ammonia, nitrites, and nitrates. These samples were received from all parts of the State, and included all classes of surface water, rivers, ponds, and reservoirs. They were examined repeatedly during the months of June, July, and August, 1888.

The results may be briefly stated as follows: The organic matter in suspension decays in about seven days, as shown by the increase in "free ammonia." In about fourteen days this "free ammonia" has disappeared, and nitrite has taken its place, reaching a maximum in about twenty-one days. Later the nitrite, too, disappears, and in twenty-eight days or more all the nitrogen has been converted into the form of nitrate. When the suspended matter is removed by filtration through paper or by precipitation with alumina, no change occurs unless free ammonia were

* Investigations upon Nitrification and the Nitrifying Organism, by Edwin O. Jordan and Ellen H. Richards. Special Rept. Mass. St. Bd. Health, Part II. (1890).

present at the outset. . . . It has long been known that the first step—the decomposition of nitrogenous matter and consequent production of ammonia—is due to the vital activity of bacteria. The early experiments of Schwann and Schultze (1839), and the later and thoroughly conclusive work of Pasteur, showed that putrefaction of organic matter is brought about solely by the small vegetable organisms known as bacteria. Even after this fact became generally known, it was some time before the importance of the complete range of this discovery was suspected. It was still maintained that the process of nitrification proper—the oxidation of ammonia to nitric acid—was of a purely chemical nature, although the burden of proof was soon thrown on those who upheld this view. The close dependence of nitrification upon a rather narrow range of temperatnre, the cessation of the process on the addition of antiseptics, the operation of "seeding" one solution with another, the impossibility of effecting rapid nitrification by chemicals, the analogous phenomena of putrefaction—all pointed clearly to the fact that nitrification depends on the presence of living organisms.

The first conclusive proof that such was the case, however, came from the work of Schloesing and Muntz in 1877. The work of these observers rendered it practically certain that living organisms of some kind are the true agents of nitrification. "It now remains for us," they said, "to discover and isolate the nitrifying organisms." Schloesing and Muntz, in their subsequent investigations, believed that they had succeeded in making this discovery; but in view of the facts of modern bacteriology we are unfortunately unable to assign much value to this part of their work. It is not easy to satisfy one's-self that Schloesing and Muntz ever worked with really pure cultures of isolated species. While the work of these investigators established beyond all question the fact that nitrification, like the analogous phenomena of fermentation and putrefaction, is caused by living organisms, it left entirely open the precise nature of these organisms.

The first experiments with species of bacteria isolated by modern methods, and therefore undoubtedly pure cultivations, are those recorded by Heraeus. Heraeus experimented with fourteen well-knowu species of bacteria, and with about as many others freshly isolated by himself from water and soil. He cultivated these in an ammoniacal solution, and obtained in the case of several familiar species good qualitative tests for nitrous acid. Among these species were Bacillus prodigiosus, the Finkler-Prior bacillus, the bacillus of typhoid fever, the anthrax bacillus, and others. Heraeus concludes that all these organisms possess oxidizing powers, since they are thus apparently able to oxidize ammonia to nitrous acid.

The work of Adametz and Frank, ou the other hand, did much to offset this positive result reached by Heraeus. They fouud, as other investigators had found before them, that the introduction of a small quantity of garden soil iuto an ammoniacal solution would produce rapid nitrification. The various species of bacteria, however, which they isolated from this soil, and introduced as pure cultures into sterilized ammoniacal solutions, refused to nitrify. In no case was more than a trace of nitric acid observed. Frank was so influenced by his continued negative results that at a later date he went so far as to deny that living organisms had anything whatever to do with nitrification. This sceptical attitude seemed for a time to be fully justified by the experiments of Celli and Zucco. It was soon, however, demonstrated again by several skilful investigators that nitrificatiou could not be accounted for by purely chemical influences. There was, nevertheless, no cessation in the publication of negative results. The work of Heraeus was extended and elaborated by P. F. Frankland and by Wariugton. Frankland failed entirely to obtain any evidence of oxidation of nitrogen by individual species of bacteria, and on this point came into direct conflict with Heraeus.

. . . .

Not only is the nitrifying organism present in Boston tap-water, . . . but it appears to be equally common in water from all parts of the State of Massachusetts. So far as our experience has gone, any natural water containing the ordinary amount of free or albuminoid ammonia contains also the nitrifying organism, as is shown by our long series of tests. In these natural waters the nitrifying organism seems to be under wholly normal conditions, and to be abundantly able to effect the oxidation of the small quantities of nitrogen usually present in these waters.

Waters that contain high "albuminoid ammonia," in cases where this "ammonia" comes from the nitrogen in infusoria, algæ, etc., go through the same changes as those which contain "free ammonia," but more slowly. The organisms in time die, the bacteria set free the nitrogen of their bodies, forming free ammonia, and then in turn nitrites and nitrates.

It might, perhaps, be reasonably expected that, since the nitrifying organism is undoubtedly present in all these waters, an examination of gelatin plate cultures of these waters would reveal some particular kind or kinds of colonies common to all, and in that way aid in sifting out the nitrifying organisms. Our experience has shown, however, that such a hope is unfounded. So far as the inspection of gelatin plate-cultures enables us to judge, no one kind of colony is common to all these waters. This fact, on the surface, seemed to favor the view that the power of nitrification was not the property of any particular organism, but was very likely possessed in common by a number of kindred species. . . .

There was . . . one possible explanation of our failure to reach consistent positive results by the use of species of bacteria isolated by the method of gelatin plate-culture. It might be that the nitrifying organism did not grow on gelatin. Everything seemed to point in this direction, and the belief was further strengthened by a very significant fact observed about this time. We had known for some time that in the history of the filter-tanks at the Lawrence Experiment Station speedy nitrification was always coincident with a marked decline in the numbers of bacteria. The effluents discharged from the filter-tanks, although high in nitrates, were low in bacteria; and, moreover, the more complete the nitrification, the fewer were the bacteria in the effluent.

We also observed that, in an ammoniacal solution which is seeded with ordinary pond-water containing several species of bacteria, there is during the first few days a rapid multiplication of the contained germs. Nitrification, however, does not as a rule begin until from ten to fourteen days have elapsed. By the time nitrification begins, the numbers of bacteria, as shown by gelatin plate-cultures, have begun to decline; and, while the nitrogen in the form of nitrites in the solution is increasing, the numbers of bacteria are as steadily diminishing. Thus, in one instance, an ammoniacal solution, four days after its inoculation with a cubic centimetre of Cochituate water, contained 3,762,000 bacteria per cubic centimetre. Nitrification had not yet begun. When the first signs of increasing nitrites appeared, the numbers of bacteria had sunk to 19,200; and when the nitrites reached their maximum, the bacteria, shown by gelatin plate-cultures, were only 9,454. It was certainly difficult to understand why nitrification, a process apparently dependent upon the life and activity of bacteria, should seem to flourish best under conditions in which bacteria were perishing. If, however, it were assumed that the nitrifying organism could not grow in the usual gelatin media, all the perplexing results above recorded could be more easily explained. Under these circumstances it was natural for us to make such an assumption.

There was, of course, the possibility that the nitrifying organism, by its growth on gelatin, had lost its peculiar property; but it did not seem to us likely that so fundamental a property could be parted with in so short a time. However that might be, we determined to test the other hypothesis first, since we believed it to be the more probable of the two. Accordingly experiments were begun to attempt to isolate the nitrifying organism by the method of dilution. This is the method that was commonly used by investigators in bacteriology before the invention of solid culture-media. It has, as is well known, serious practical as well as theoretical drawbacks. In our practice a small portion of an actively nitrifying solution is transferred on the loop of a sterilized platinum needle to a sterilized ammoniacal solution, and when nitrification is thus induced in the second solution a fresh transfer is made from this to a third, and so on. Rigid precautions have been taken to avoid the introduction of foreign germs.

. . . .

Hardly were these experiments well under way before our interest in this method of procedure was stimulated by the publication of communications by Percy F. Frankland, and Grace Frankland, and by Robert Warington.*

* The Chemical News, vol. lxi., p. 135, March 21, 1890.

The Franklands, having reached a conclusion similar to our own regarding the behavior of the nitrifying organism in gelatin, had also attempted to isolate the nitrifying organism by the dilution method, and had succeeded in the attempt. They state, in their abstract of the paper read before the Royal Society, that "after a very large number of experiments had been made in this direction, the authors at length succeeded in obtaining an attenuation consisting of about 1-1,000,000th of the original nitrifying solution employed, which not only nitrified, but on inoculation into gelatin-peptone, refused to grow, and was seen under the microscope to consist of numerous characteristic bacilli, hardly longer than broad, which may be described as bacillococci."

Warington's communication entirely confirms that of the Franklands, in so far as it relates to their earlier and negative results. He had not, however, at the time of writing, succeeded in isolating the nitrifying organism.

A paper by Winogradsky followed soon after. He appears to have discovered independently a nitrifying organism, and attributes his success largely to his microscopic examinations of the nitrifying solutions, and to his use of solutions devoid of organic matter. The following is the composition of the liquid finally adopted by him:

	Grammes.
Ammonium sulphate	1
Potassium phosphate	1
Water from the lake (at Zurich, "très pure")	1,000

Each portion of 100 cubic centimetres received in addition .5 to 1 gm. of basic magnesium carbonate, suspended in distilled water. Winogradsky found that this layer of magnesium carbonate at the bottom of each flask afforded an excellent gathering place for flocks of the nitrifying organism. The "nitric ferment" does not, as the Franklands had already shown, grow well upon ordinary gelatin plate-cultures; and this is probably the cause of the failure of all previous experimenters to isolate the special ferment. For Winogradsky's detailed description of the nitric ferment, and for a statement of his peculiar views concerning its function, "*de regulariser la circulation du carbone sur notre planete,*" we must refer to his original papers.*

Before receiving Winogradsky's paper, in the spring of 1890, we had been using in our work, at the suggestion of Mr. Allen Hazen, an ammoniacal solution of the following composition:

	Grammes.
Ammonium chloride (resublimed)	1.9070
Sodium carbonate	3.7842
Sodium phosphate	.2000
Potassium sulphate	.2000

Proceeding with this solution by the method of dilution, we at length succeeded in isolating a nitrifying organism. A flask was first inoculated with a few grains of sand from Tank No. 13, at the Lawrence Experiment Station, and when nitrification was at its height in this solution a small portion was transferred from this to a second flask, and so on. After a large number of unsuccessful attempts, two solutions were finally obtained which nitrified well, but gave no growth upon ordinary gelatin plate-cultures, although the plates were allowed to stand for seven days. Microscopic examination of these solutions showed them to be inhabited by a particular form of bacillus, and apparently by that alone. These bacilli are short, of a slightly oval shape, and vary from $1.1\,\mu$ to $1.7\,\mu$ in length; they are about $0.8\,\mu$ to $0.9\,\mu$ broad. They are grouped very characteristically in irregular clumps, and are held together by a jelly-like material. Each aggregation is indeed a typical zoöglœa. The aggregations of bacteria were found chiefly on the bottom of the flasks, as was also the case with the organism described by Winogradsky. These masses of zoöglœa obtained as a pure culture from a nitrifying solution, resemble significantly the zoöglœa discharged in considerable quantities from the filter-tanks at Lawrence. . . . The bacilli stain with some difficulty with the usual aniline dyes. We have not observed independent movement. Owing to the lack of the

* Annales de l'Institut Pasteur, Tome iv., 1890, No. 4, p. 213; No. 5, p. 257.

usual means of diagnosis, it is difficult to determine in a short time whether this species is the same as the one described by the Franklands and by Winogradsky. On one important point there appears to be a difference between our results and those reached by the above-mentioned investigators. The organism discovered by them oxidizes ammonia to nitrite, but carries it no further. Our own flasks give complete oxidation to nitrate. Whether this be due to a difference of conditions, a difference in the virility of the organisms, or a specific difference in the bacteria, we are not at present prepared to say. The short time at our disposal has made it impossible to settle this and many other questions to our own satisfaction. We are not even prepared to say that there may not have been a mixture of two or more species in our flasks, all agreeing closely in morphological characters, and in giving no growth on gelatin, but differing in important physiological respects. Further investigation is necessary to settle this and other important points regarding the relations of this organism to the process of nitrification.

Whether or not we accept the views of Winogradsky, it is certainly worthy of remark, as he observes, that an organism should exist, which, without chlorophyll and in the apparent absence of organic nitrogen and of organic carbon, should be able to multiply and thrive upon wholly inorganic compounds. It may well be doubted, we think, whether this is really the case. It seems more reasonable to suppose that exceedingly minute quantities of organic nitrogen and carbon are actually present, and escape detection by our present methods of chemical analysis, although in reality sufficient to nourish generations of bacteria.

Our own experience, as well as that of previous investigators, seems to be a warning against a too confiding use of the gelatin plate-culture in bacteriological work, since in this instance such confidence has left us for a long time in ignorance of a common and widespread as well as highly important organism.

Disappearance of a Portion of the Nitrogen.

In the practical working of intermittent sand-filters at Lawrence, it has been found (1) that during the first few weeks of service much less nitrogen came away in the effluents than was applied in the sewage; (2) that nitrification is usually somewhat more active in the spring and early summer than at any other season, there being at this time frequently an excess of nitrogen in the effluent over that applied in the sewage, caused by the oxidation of organic matter stored in the filter; (3) that as a whole less nitrogen flows away in the effluent than is applied in the sewage. The Report of the Massachusetts State Board of Health for 1891 states that Filter No. 1 stored fifteen per cent. of the nitrogen applied in four years of service, and other filters even more. The storage of nitrogen seems to decrease from year to year, but the observations have not been sufficiently extended to determine whether the storage would cease before the filter became too much clogged for use. The experimental sand-filters at Lawrence possess the power of self-cleansing and continue to act efficiently for a long time, but to obtain the best results it is probable that the surfaces of such filters require raking over at convenient intervals, while after two or three years, at least, the top portion of the sand should probably be removed.* With ample filtering areas, the beds may be given a long rest, instead of removing the sand.

* For extended discussion of this point see Chapter XIV.

Practical Experiments.

In the course of the work at Lawrence a number of experiments were made in regard to the effect of different substances upon nitrification. The following is a brief account of the more important:

(1.) In April, May, and June, 1889, instead of sewage, there was applied daily to Tank No. 12 (one of the small tanks) $1\frac{1}{2}$ gallons of water, to which had been added enough baked and pulverized egg albumin to make 2.8 parts of nitrogen per 100,000. The first application of this mixture was made April 18th.

Egg albumin is nearly insoluble in water, and the object of this experiment was chiefly to determine to what extent it would be rendered soluble and converted into free ammonia, or carried another step and become nitrified, in passing through the filter. The experiment was interrupted before completion, and the results in consequence are somewhat uncertain. The indications are, however, that about 61 per cent. of the total nitrogen contained in the albumin applied was rendered soluble and converted into nitrates. There are no means of determining how much of the insoluble nitrogenous matter was stored in the sand, though comparing with results obtained with sewage, it appears probable that but little was stored.

This experiment was repeated from July 10 to August 7, 1889, when there was applied three gallons of water per day, containing baked and pulverized blood albumin sufficient to supply 1.04 part of nitrogen per 100,000. This experiment was also somewhat uncertain as to the actual results obtained, though the indications are that about 90 per cent. of the total nitrogen of the mixture appeared as nitrates in the effluent.

(2.) We have already referred, in Chapter I., to the experiments upon the passage of *Bacillus prodigiosus* through the sand-filters, and we will now describe some further phenomena developed by that experiment.

In order to apply *Bacillus prodigiosus* a litre of bouillon, containing a pure culture of many millions, was mixed with water and applied to Filter No. 12 on the morning of August 7, 1889. On the morning of August 8th the number of bacteria found in the effluent was 60 per cubic centimetre. At 1 P.M. of the same day the number was 13,440; two hours later the number was 58,000; at 5 P.M. the number had increased to 81,700; and at 9 P.M. the count gave 108,100. On August 9th the number of bacteria was high in the forenoon, reaching 12,964 at noon, and decresaing to 494 at nine in the evening. At 9 P.M. on August 10th the number was 3, and three counts on August 11th averaged 4.

We have here a large increase in the amount of the food material added to the tank, followed by, apparently, a great increase in the number of bacteria in the tank, as indicated by the increase of number in the effluent. The time, however, of such increase was quite short, as the effect of adding the extra food material appears to have spent itself on August 10th.

The bouillon employed in this experiment consisted of beef-tea enriched with peptone, as ordinarily prepared for a culture-medium by bacteriologists. Peptone, the principal nutritive constituent, is soluble and therefore specially available as bacterial food. It is probably superior in nutrient value to most of the substances found in sewage.

On September 20, 1889, the same quantity of bouillon, as previously used on August 7th, was again applied. The bouillon of this second experiment was of the same quality as that used on August 7th, except that it was sterilized so that it contained no bacteria. On September 18th, 19th and 20th, before applying the bouillon, the average number of bacteria in the effluent was 199; on the morning of September 21st the number was found to be 54,600; at 1.55 P.M. of the same day the number counted was 57,600; at 9 P.M. it was 26,400. The greatest number on September 23d was 4,485. On September 26th the number at the time of greatest flow was 1,820; on October 2d the number at the same time was 736.

In addition to the experiments with bouillon and peptone mixture just described, experiments had also been previously made in the month of March, 1889, by the application of a solution of peptone alone to Tank No. 11. The results were essentially the same as those found later with Tank No. 12. In every case the application of the nutrient mixture was first followed by a considerable increase in the number of bacteria appearing in the effluent, followed later by a decrease in the bacteria in the effluent with increased nitrification.

The effect of applying a nutrient mixture to an intermittent filter is summarized in the Special Report (page 856) as follows:

> At first there is an increased discharge of bacteria and an incomplete oxidation, but this condition gradually changes to one of almost complete oxidation, and the discharge of very few, if any, bacteria. This series of events appears to be due to the temporary over-feeding of the filter, and consequent increase of the bacteria, followed by a new balance of supply and demand. It follows also that peptone is readily and completely oxidized by micro-organisms.

(3.) Filter Tank No. 13 received sewage for nearly a year previous to January 14, 1889, at the rate of 60,000 gallons per acre per day. Beginning on that date, at which time the tank was giving a perfectly nitrified effluent, a solution of ammonium chloride in water, containing 1 part ammonia per 100,000, was substituted for the sewage. Enough

sodium carbonate was mixed with this solution to combine with the chlorine of the ammonium chloride, and also with the nitric acid equivalent to the ammonia. Nitrification was complete from the first, the effluent being not only almost free from ammonia, but containing nearly all of the nitrogen applied as nitrates.

The strength of the solution was increased from time to time, until on April 22d it contained 34 parts per 100,000 of ammonia.

After increasing the amount applied complete nitrification was not at once obtained, but the effluent contained ammonia and nitrites. Later the ammonia disappeared from the effluent, to be followed by the nitrites, while increased development of the nitrates went on, until finally a nearly complete nitrification was obtained.

The effect of an excess and deficiency of alkali was also experimented upon with Tank No. 13. From July 2 to August 5, 1889, the proportionate parts of the mixture added to this tank was 4 ammonium chloride to 5 of sodium carbonate. This gave sodium carbonate in excess of the amount required to neutralize the ammonium chloride. Nitrification was not in the least interfered with. The excess of sodium carbonate passed through without change, with no other result than to increase the alkalinity of the effluent.

Beginning October 8th, the proportion added was 4 of ammonium chloride to 3 of sodium carbonate, in which there was a deficiency of alkali. The result was an almost total stoppage of nitrification, which, however, after a time began again, but did not become complete.

An unexpected result of the experiment with deficiency of alkali, was the production of an enormous quantity of nitrites.

It appears, then, from these experiments that an excess of alkali is without effect upon nitrification, but on the other hand, with an insufficient quantity nitrification is incomplete, the effluent containing ammonia and nitrites, the latter often in large quantities.

(4.) The effect of acid upon nitrification was experimented upon with Tank 15 A, which is one of the small tanks, filled with very coarse gravel, the stones ranging between $\frac{3}{4}$ and $1\frac{1}{4}$ inch in diameter. Before placing in the tank the gravel was carefully washed in order to remove any sand, earth, or organic matter which might otherwise remain attached to the stones. The empty space in this tank amounted to about 37 per cent. of the whole. In October, 1889, this tank was purifying sewage at the rate of 20,000 gallons per day with fair nitrification. Beginning October 22d, sulphuric acid was added to the sewage, in quantity equal to 22.54 parts per 100,000 of sulphuric acid in the solution. The result of this treatment was a great increase of free ammonia, with fluctuation of the albuminoid ammonia and decrease of nitrates in the effluent. The treatment was continued for four months, during all of which time some nitrification continued,

although gradually decreasing in amount. Summarizing the result of this experiment, Mr. Mills says (Special Report, page 563):

> We learn from this experiment that sewage containing a large percentage of sulphuric acid may have a large part of its organic matter removed by intermittent filtration for a considerable time; so that we may not expect an unfavorable result if sewage having an excess of acid be occasionally applied to a filtration area; but, if it is constantly applied, it should be neutralized by lime or some alkali.

The effect of using limestone to counteract the acidity of the sewage was subsequently further experimented upon in Filter No. 17 A, in which a little limestone was mixed with the upper layers of the filtering material, and strong lye and sewage applied for over a year. The effluent showed results comparable with those from normal sewage filtered, under similar conditions, through sand without limestone.

(5.) The effect of saltpetre upon nitrification was also experimented with in Tank No. 15 A. The result was that when saltpetre was dissolved in the sewage to the amount of 72 parts of nitrogen per 100,000, the quantity of nitrates in the effluent increased from 2.01 parts per 100,000 two days before the saltpetre was applied, to 64 parts per 100,000 four days after the application. The saltpetre was discontinued after five days, and in twelve days from the first application the nitrates had fallen to 15 parts per 100,000.

(6.) Experiments were made as to the effect of common salt upon nitrification in Tank No. 11, which, as already stated, had been used for the experiments with the peptone solution. Beginning July 2, 1889, a solution of ammonium chloride with a suitable amount of sodium carbonate in water was applied to this tank, the solution containing 2 parts of nitrogen per 100,000. At the end of a month the effluent contained nearly all the nitrogen applied. On August 8th, common salt was added in such quantity that the charge contained 1,200 parts of chlorine per 100,000. Nitrification was checked and the solution passed through the filter almost unchanged. August 27th, the addition of salt was suspended, the charge from that time until September 9th being the same as previous to the addition of the salt. On September 9th nitrification was again complete. Salt was again added, but in much smaller quantities than before; such addition being followed by a decrease of the nitrates in ten days from 2.08 parts per 100,000 to 0.15 part. Upon continuing the same solution eight days longer the nitrates increased 1.34 part per 100,000. The chlorine at this time was 127.1 parts.

The quantity of salt in the daily application was then increased for three weeks, until the chlorine amounted to 367.0 parts; during this time the nitrates decreased to 0.2 part; upon again gradually increasing the quantity of salt the nitrates also increased. On December

14th chlorine reached 1,306.0 parts and the nitrates were 1.0 part per 100,000.

In regard to the practical bearings of this experiment Mr. Mills says:

By gradually increasing the amount of salt in the solution to a little more than was applied in August at once, without time for a gradual adaptation of the filter to the work required of it, we find a very different result. In August the same quantity of salt caused nitrification to cease, and allowed the ammonia to come through the filter nearly unchanged. By the gradual application of the salt in increasing quantities, we now find that, when the same quantity is applied, the ammonias are reduced to about 12 per cent. of those which came through in August; and the nitrates, which were zero, are now equal to one part per 100,000. From this we see that by properly preparing the filter, a solution of ammonia may be quite satisfactorily purified by nitrification, even when it is as salt as ordinary sea-water. Upon rapidly increasing the amount of salt, from December 14, 1889, to January 8, 1890, to about four times that which it contained on December 14th, so that it was nearly three times as salt as ordinary sea-water, the nitrates were very much reduced. Obtained in the usual way they amounted to .0600 part; but it is to be noted that the method of determining nitrates, when the solution contains these very large amounts of salt, gives results which are too low. From these results we may conclude that quite satisfactory nitrification may result when applying to a filtration area sewage containing a very large amount of salt, if only it be applied with reasonable regularity.

(7.) The effect of sugar upon nitrification was experimented with in Tank No. 12, which had also been used for filtration of sewage in the experiment with egg-albumin and water. Beginning October 23, 1889, and continuing to December 8th, three gallons of city water containing granulated sugar equal to 100 parts per 100,000 of the solution were applied daily. The result was that nitrification decreased immediately. The greater part of the sugar passed through the tank unchanged and in six weeks' time the effluent contained three-fourths of the applied sugar.

On December 9th, three gallons of sewage were applied daily, without any sugar. Nitrification was resumed at once, and in five days' time the nitrates amounted to 0.22 part. During this period the temperature of the effluent varied from 49° to 40° F. In twelve days the nitrates amounted to 0.86 part.

Beginning January 1, 1890, sugar was applied to the sewage to the amount of 10 parts in 100,000; on the 13th, this amount was increased to 20 parts. The effect was to slowly reduce the amount of nitrates in the effluent to 0.08 part on January 31st, without any increase of ammonias. From this time the nitrates increased, until they reached 1.1 part on February 28th, the effluent then contained less than one per cent. of the amount of sugar applied, while in November and the early part of December, from one-third to three-fourths of the amount applied passed through.

From this experiment it appears that a considerable quantity of sugar, when first applied to intermittent sand-filters, will cause a decrease of nitrification without increase of ammonias. If, however, such

a filter can be gradually adapted to the special work of nitrifying sugar, the nitrates are formed about as completely as when sugar is absent.

In the special case under consideration after the adaptation of the filter to the work during the low temperature of winter, a satisfactory purification was finally attained of 60,000 gallons of sewage applied per acre daily.

(8.) The effect of an amount of free oxygen upon nitrification was also experimented with in Filter Tank No. 14, which was a small tank filled with sand of the same quality as that in Tank No. 1. This tank had been used, previous to the special experiment, for sewage filtration in the ordinary way for about a year.

For the special experiments on the effect of free oxygen upon nitrification, the tank was fitted with a trap at the bottom, and a cover to the top, with mercury seal, which made it air-tight. A pressure-guage was connected with a small faucet. The daily application of sewage was put in through a large funnel, with a stop-cock to prevent the admission of air, and a perforated plate under the cover distributed the sewage over the surface. The trap at the bottom allowed the effluent to flow away, but prevented the ingress of air to the tank with ordinary pressures. From February 21st to 28th, nine gallons of sewage were applied daily. During this time there were a number of leaks, and there must have been a good supply of air. Nitrification was nearly stopped. On March 1st, the tank was shown, by the pressure-guage, to be perfectly tight. The same daily application of sewage was continued and in a week nitrification had stopped, and the effluent flowed away little better than crude sewage. On March 16th, the cock for admitting sewage was left open in order to ventilate the top of the tank. The effluent still remained the same, and on March 27th the cover was taken off. This still did not afford sufficient air, the tank having become clogged by the organic matter which had accumulated during the time when the air was excluded. On April 2d, one-half inch of the accumulation was removed from the surface; and an aspirator attached to one of the side faucets, near the bottom. Thereupon the effluent rapidly improved, and in two weeks nitrification was again nearly complete. During April and the following months a number of different experiments were made as to the effect of free oxygen upon nitrification with this tank. The net result of the whole series is to enforce the proposition that nitrification cannot take place in sand-filters without the air in the spaces of the filter contains oxygen. The experiments also show that a small amount of oxygen, in the air in the spaces of the filter, is nearly as effective as a larger quantity, provided the air is changed often enough to insure the presence of some oxygen at every point.

PRESENT THEORY OF NITRIFICATION.

We have now exhibited some of the more interesting points in connection with nitrification in its application to sewage disposal. By way of presenting the present theory in a concise form it may be stated that the ascertained facts indicate that nitrification takes place in two stages, each characterized by a distinct organism. The office of one of these is to convert ammonia into nitrite; while the other converts nitrite into nitrate, whence we have the nitrous and nitric organism or ferments.* Both are present in ordinary soils in enormous numbers; they are also present or quickly develop in sewage, which may be considered a nutrient medium for them by reason of containing a large amount of their natural nitrogenous food.

As to which organism will develop in any particular case in the greater quantity will depend upon the existence of a number of special conditions, some of which are not yet well understood. In the meantime what we do definitely know indicates that the two organisms may be, according to Warington, separated by "successive cultivations in solutions of special composition favoring the development of either." By employing a solution containing potassium nitrate, but no ammonia, we may obtain the nitric organism alone; or by employing an ammonium carbonate solution a few cultivations give us the nitrous organisms in a pure state. The significance of these facts in relation to sewage purification is partially exhibited in the Lawrence experiments already given.

DENITRIFICATION.

We have seen from what has preceded that soil possesses the power of nitrification in the highest degree. Under certain circumstances, however, it possesses the power of rapidly destroying nitrates, and as such destruction may have its bearing on the results of sewage purification it becomes of importance to understand the circumstances under which it takes place, especially in view of the fact that sewage itself will destroy nitrates in waters containing them, as first observed by Dr. Angus Smith in 1867, who also pointed out that the nitrogen of the nitrate was, in the case of denitrification, by sewage, evolved as gas. We have then, as the first condition for denitrification, the presence in solution of nitrates together with oxidizable organic matter. The power of nitrification is, however, not lost when denitrification has

* For photographic illustrations of the nitrous and nitric organisms see Experiment Station Bulletin, No. 8, Lectures on the Investigations at Rothamsted Experimental Station, by Robert Warington, F.R.S., delivered before the Assn. of Am. Ag. Colleges and Ex. Stations at Washington, Aug. 12-18, 1891, Plates VI., VII., and VIII.

taken place through the action of organic matter; in due course the organic matter disappears and nitrification again proceeds.

Denitrification is not in any sense a chemical reaction; on the contrary, like nitrification, it can only take place in the presence of a living organism. The effects of micro-organisms upon solutions containing a nitrate and organic matter have been studied by a number of observers in the last few years. The result is the determination of from 20 to 30 species of bacteria which produce some kind of a reducing effect, although only two species, *Bacterium denitrificans* α and β have been found to certainly possess the property of reducing nitrates to nitrogen gas. The most common form of reduction is from nitrates to nitrites.

Denitrification may also be made to take place by the simple process of excluding oxygen, as, for instance, by saturating a soil with water.

In the foregoing we have set forth some of the more important facts relating to the subject of nitrification. In the chapter on Intermittent Filtration the necessary conditions for nitrification in its application to sewage purification are more fully discussed.*

* In addition to the papers cited in the chapter, the following partial list of "Rothamsted" papers on nitrification and allied subjects, as given by Mr. Warington in his Washington lectures, *loc. cit.*, may be consulted:

On Nitrification.—*Jour. Chem. Soc.*, 1878, 44.

On Nitrification, Part II.—*Trans. Chem. Soc.*, 1879, 429.

On Alterations in the Properties of the Nitric Ferment by Cultivation.—*Report British Association for the Advancement of Science*, 1881, 593.

On the Determination of Nitric Acid by Means of its Reaction with Ferrous Salts, Part I.—*Trans. Chem. Soc.*, 1880, 468; Part II., *ibid.*, 1882, 345.

On the Determination of Nitric Acid in Soils.—*Trans. Chem. Soc.*, 1882, 351.

Determinations of Nitrogen in the Soils of some of the Experimental Fields at Rothamsted, and the Bearing of the Results on the Question of the Sources of the Nitrogen of our Crops.—*Report American Association for the Advancement of Science*, 1882.

New Determinations of Ammonia, Chlorine, and Sulphuric Acid in the Rain Water Collected at Rothamsted.—*Jour. Roy. Agr. Soc.*, 1883, 313.

The Nitrogen as Nitric Acid in the Soils and Subsoils of some of the Fields at Rothamsted.—*Jour. Roy. Agr. Soc.*, 1883, 331.

On Nitrification, Part III.—*Trans. Chem. Soc.*, 1884, 937.

On the Action of Gypsum in Promoting Nitrification.—*Trans. Chem. Soc.*, 1885, 758.

On some Points in the Composition of Soils, with Results Illustrating the Sources of the Fertility of Manitoba Prairie Soils.—*Trans. Chem. Soc.*, 1885, 380.

On the Distribution of the Nitrifying Organisms in the Soil.—*Trans. Chem. Soc.*, 1887, 118.

A Contribution to the Study of Well Waters.—*Trans. Chem. Soc.*, 1887, 500.

The Chemical Actions of some Micro-organisms.—*Trans. Chem. Soc.*, 1888, 727.

On the Present Position of the Question of the Sources of the Nitrogen of Vegetation, with some New Results and Preliminary Notice of New Lines of Investigation.—*Phil. Trans. Roy. Soc.*, 1889, *B.* 1.

The History of a Field Newly Laid Down to Permanent Grass.—*Jour. Roy. Agr. Soc*, 1889.

The Amount of Nitric Acid in the Rain Water at Rothamsted, with Notes on the Analysis of Rain Water.—*Trans. Chem. Soc.*, 1889, 537.

On Nitrification, Part IV.—*Trans. Chem. Soc.*, 1891, 484.

CHAPTER XI.

CHEMICAL PRECIPITATION.

Definition of the Process.

If we refer to Table No. 32, on page 152, we observe that a portion of the organic matter of sewage is in suspension only. When sewage is allowed to stand for a few hours a part of the suspended matter will be deposited at the bottom, through the action of sedimentation; but such action is ordinarily quite restricted in its range and cannot be relied upon by itself to effect the efficient purification of sewage. If, however, certain chemicals are added to the sewage, an insoluble precipitant is formed, which, under favorable circumstances, may carry down with it all the suspended matter, as well as a portion of the dissolved organic matter. The addition of the chemicals, together with the working of the various appliances for grinding and mixing of the same, the decanting of the effluent and the caring for the sludge, all constitute what is known as the chemical treatment of sewage, the complete process being, in reality, partly chemical and partly mechanical.

Reagents.

An enormous number of chemical agents have been, at various times, proposed for this purpose; but experience has apparently narrowed the really useful ones down to three, the others having proven either worthless or too expensive for general use. Those chiefly used at the present time are lime, sulphate of alumina, and ferrous sulphate. Ferric sulphate has also been experimented with at the Lawrence Experiment Station, and found to be, in certain particulars, superior to the others; but as yet this salt has not been extensively used in actual practice. The chemical reagents are used, either singly or in combination, as may be required to fit the case of each particular sewage undergoing treatment.

Theory of Precipitation.

The action of these various substances in causing a precipitation of the organic matter is not definitely understood, though, in a general

way, we may say that the precipitating effect is exerted in accordance with the following:

In the case of lime there is (1) a combination of some of the lime with free and partially combined carbon dioxide to form an insoluble carbonate of lime; and (2) there is probably a further combination of an additional part of the lime with a portion of the organic matters in solution. The insoluble substances so formed sink to the bottom, carrying with them the major portion of the suspended matter in the sewage in the form of sludge.

Sulphate of alumina exercises a precipitating effect by virtue of (1) a combination of the sulphuric acid with lime and other bases in the sewage, whilst (2) alumina hydrate, forming a flocculent precipitate, entangles and carries down the suspended organic matters. Most of the recent authorities have recommended a combination lime and sulphate of alumina treatment, the proportion in which they are used to be such as to yield as nearly as possible a neutral effluent; we shall learn, however, from the results of the Lawrence experiments that a combination lime and sulphate of alumina treatment has little to recommend it. Theoretically frequent tests should be made of the quality of the sewage as delivered at the disposal works, and the chemical treatment adapted to the varying conditions of flow. Practically, also, this has been found to be the best method of procedure, and at Worcester such tests are made and the application of the chemicals gaged, in accordance with results thereof, at times as often as once every half hour. An extended account of such tests is given in Chapter XXVII., descriptive of the Worcester Disposal Works, to which the reader is referred for further information on this point.

When iron salts are added to sewage which is either naturally alkaline or to which an alkali, as lime, has been artificially added, a flocculent hydrated oxide is formed as a precipitate, which carries down with it the suspended organic matter, as well as a portion of the dissolved.

Conditions Essential for Success.

The conditions which insure the best results from chemical treatment may be stated as:

(1) That the sewage be treated while fresh.

(2) That the chemicals be added to the flowing sewage and thoroughly mixed with it before it passes into the settling tanks.

(3) That there be a liberal amount of tank space.

(4) That the arrangements for removing the sludge be such as to insure its frequent removal, for if left in the tanks until putrefaction sets in the sludge is likely to rise to the surface, giving off foul odors.

Classification of Chemical Treatments.

Leaving out of account the different methods of combining the chemicals we may classify chemical treatments as follows:

(1) Intermittent treatment in shallow tanks from 5 to 8 feet deep, in which, after the addition and incorporation of the chemicals, the sewage is allowed to remain undisturbed until the completion of the process.

(2) Continuous treatment in a series of tanks through which, after the addition and incorporation of the reagents, the sewage is allowed to flow slowly; crude sewage, with freshly added chemicals passing in at one end, and purified effluent passing out at the other.

(3) Vertical tanks, through which, after the addition of the chemicals, the sewage rises slowly.

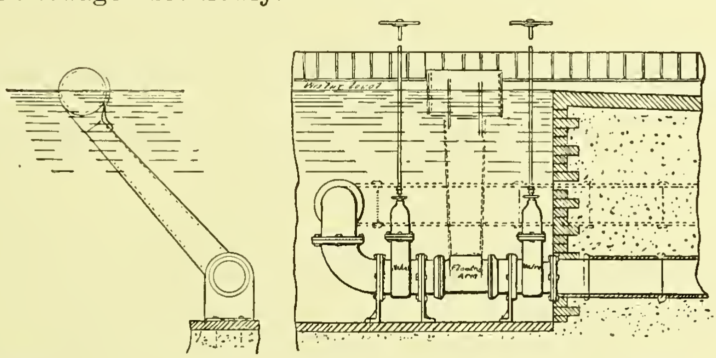


Fig. 11.—Floating Arm for Decanting Effluent from Tanks.

There are a number of variations of these three systems, but none of them are important enough to justify further subdivision into classes.

In England, where chemical treatment was first developed, the systems of intermittent and continuous treatment in shallow tanks are used exclusively. Tanks of both systems possess certain features in common, as, for instance, such arrangement of a gang of tanks as will admit of cutting out any one of the series for cleaning and repairs without interfering with the balance of the gang.

Capacity of Precipitation Tanks.

In operating precipitating tanks intermittently, it is necessary to observe certain principles, namely, the amount of tankage should be sufficient to allow the sewage to stand at least one hour, in order to insure fairly thorough precipitation. With some treatments the time required for complete precipitation is longer than one hour; hence it is

desirable before deciding in any given case the amount of tank capacity to ascertain what form of treatment is best suited to the particular sewage in hand. The Lawrence experiments on chemical purification furnish a large amount of useful information on this point. In computing the total tank capacity it is necessary to take into account the time required for filling, precipitating, and emptying, the maximum flow of sewage to be expected being taken as the basis of the computation. This portion of the subject still lacks scientific treatment, no good generalization of the relation between the quantity of sewage to be treated and amount of tank capacity required having yet appeared.

As an empirical statement, based on practice, we may say the total tank capacity for disposing of the sewage, from systems which are arranged with reference to receiving a portion of the rainfall, should be nearly 50 per cent. of the average daily flow, an allowance of this amount giving some leeway for contingencies when required. For further information on this point see Chapter VII., on Quantity of Sewage and Variations of the Rate of Flow. In any case, it is necessary to provide enough tanks, so that when required one or more may be out of service for cleaning or other purposes, without crowding the precipitation in the balance of the tanks.

TABLE NO. 43. — TANK CAPACITY IN RELATION TO POPULATION AND QUANTITY OF SEWAGE AT THREE ENGLISH TOWNS.

Place.	Treatment.	Population.	No. of tanks.	Flow of sewage in 24 hours, gallons.	Gallons per head of population in 24 hours.	Total capacity of tanks, gallons.	Tank capacity per head of population, gallons.	Per cent. of tank capacity to daily flow.
Bradford	Intermittent	225,000	34	8,000,000	35	612,000	2.7	7½
Coventry	Intermittent and continuous	48,000	8	2,200,000	46	1,000,000	20.8	45
Leyton	Continuous	40,000	4	1,500,000	37	1,000,000	25.0	67

When tanks are operated continuously the sewage should be thoroughly screened, in order to intercept any large masses of matter before passing into the tanks. Tanks operated on the continuous principle should be so designed as to readily admit of emptying whenever it is necessary to clean them, or to remove sludge.

VERTICAL TANKS.

The system of vertical tanks was developed in Germany, and, so far as the authors are aware, have never been used in England or the Uni-

ted States, except at the Chicago Exposition, where this form of tank has been adapted for the sewage purification works. They present the theoretical anomaly of continuous upward movement of the sewage and a downward movement of the sludge. They are, nevertheless, stated to produce an efficient purification. It is found in practice that there is, in vertical tanks, what may be termed a neutral plane of precipitation. Any organic matter which may happen to pass above this plane, as it is more thoroughly acted upon by the chemicals, slowly falls back in opposition to the upward current, to the neutral plane. The flocculent matter collecting there forms a sort of filtering medium, which assists in arresting other matter which is floating upward. When a considerable mass has collected the whole finally falls to the bottom, and the process of collection at the neutral plane again takes place. In upright tanks the sludge is generally withdrawn from the bottom, without interfering with the regular operation of the tanks; in effecting this a number of devices are applied, to which it is unnecessary to refer here. Tanks of this form possess the merit of large capacity on small ground space, and may be of use in localities where limited areas only are available.

Methods of Sludge Disposal.

Practicable methods of disposing of sludge may be classified as:

(1) The sludge may be allowed to flow or may be pumped into sludge basins, from which it is subsequently conveyed, either by gravity or steam power, to adjacent areas, to be utilized as an agricultural fertilizer.

(2) The sludge may be deposited in large open basins, surrounded by embankments, where it is allowed to remain until the larger portion of the water has evaporated or drained away, after which it is removed by carts or other conveyance, either for use as a fertilizer, or to some other point for final disposal, as in filling in low land.

(3) Liquid sludge may be run directly on to agricultural areas, and efficiently disposed of by ploughing into the soil as soon as possible.

(4) Sludge, either in the liquid state or after partial desiccation, may be mixed with combustibles, such as peat, tanbark, and sawdust, and disposed of by burning.

(5) Sludge may be mixed with earth, rubbish, vegetable mold, marl, gypsum, stable manure, leaves, or other suitable materials, to form compost heaps, and in this manner finally utilized as manure.

(6) Liquid sludge may, when disposal works are situated within reach of a large and deep body of water (and for this purpose tidewater is preferable), be disposed of by running into dumping scows which convey it to deep water where it may be dumped. The

minimum distance at which this operation may be safely performed in large bodies of fresh water, like the great lakes, which are also the source of public water supplies, is as yet entirely unknown.

(7) Sludge may be burned in a furnace of form similar to a garbage destructor, or in a garbage destructor in connection with garbage, as at Coney Island, N. Y.

(8) Sludge may be compressed by a filter press into solid cakes, in which form it may be handled and conveniently transported for use as a fertilizer.

The use of the filter press has considerably simplified the handling of sludge, which, previous to its introduction, was a source of great difficulty at nearly all precipitation works. At present filter presses are in use at only two places in this country, namely, at East Orange and at Long Branch.* For a statement of some of the results at East Orange, the reader is referred to Chapter XXIV., treating of the works at that place.†

Sludge, as it ordinarily comes from settling tanks, operated by either the intermittent or continuous system, contains from 90 to 95 per cent. water and from 5 to 10 per cent. solid matter. In upright tanks, from which the sludge is removed by pumping without interfering with the operation of the tanks, a sludge may be obtained with only 70 to 90 per cent. of water.

Methods of Mixing Chemicals.

Various methods of mixing the chemicals with the sewage are resorted to. When sewage is delivered to purification works by gravity, a salmon way, formed by placing baffle boards in the conduit, is a convenient way of obtaining a thorough mixing. When this device is employed, the chemicals, after being first thoroughly ground and mixed with water, or otherwise prepared in special small tanks, are added to the flowing sewage just before it reaches the salmon way. This method of mixing the chemicals with the sewage is illustrated in the plans of the works at Worcester and East Orange, in Part II.

* Since the above was written a filter press has been put in operation at Canton, O.

† For detailed information in regard to disposal of sludge by the use of filter presses, etc., see—

(1) On the Disposal of Sewage Sludge. By Christopher Clarke Hutchinson. Jour. Soc. Chem. Industry, Feb. 4, 1884.

(2) Composition and Manurial Value of Filter Pressed Sludge. By J. M. H. Munro. Jour. Soc. Chem. Industry, Jan. 29, 1885.

(3) Papers on Disposal of Sewage Sludge. By J. W. Dibdin and W. Santo Crimp. Trans. Inst. C. E., vol. lxxxviii., Ses. 1886-1887, Part II.

(4) Sewage Disposal Works, Crimp, Chapter VIII.

(5) Sewage Treatment and Sludge Disposal. By W. Santo Crimp, Eng. and Bldg. Recd., vol. xxvii., pp. 237-238; pp. 256-257; pp. 277-278 (Feb. 18 and 25, and Mar. 4, 1893); also abstracted in Eng. News, vol. xxix., pp. 198-9. (March 2, 1893).

A pump may also be made to do the work of mixing when required in lifting the sewage for treatment. This method is illustrated in the plans of the Mystic Valley Works, in Part II. Mixing wheels, driven either by the flowing sewage or by independent power, may also be used.

The Massachusetts Experiments on Chemical Purification.

Our scientific knowledge of the chemical purification of sewage has been largely extended by a series of experiments made by Mr. Allen Hazen, chemist in charge at the Lawrence Experiment Station, during the year 1889. The precipitants experimented with were lime, sulphate of alumina, ferrous sulphate or copperas, and ferric sulphate.

Cost of Chemicals.

Mr. Hazen states that lime, containing 70 per cent. available calcium oxide, can be bought (presumably at Lawrence) for $9 per net ton; ferrous sulphate or copperas, containing 26 per cent. ferrous oxide, at $10 per net ton; and alumina sulphate, containing 14 per cent. alumina, at $25 per net ton. A ferric salt can be made by oxidizing copperas with chlorine, or with sulphuric acid and nitrate of soda. The approximate cost of the oxides in solution is stated as follows:

Aluminum oxide	9 cents per pound.
Ferric oxide	3 cents per pound.
Ferrous oxide	2 cents per pound.
Calcium oxide	$\frac{2}{3}$ cent per lb.

In the experiments, the results are generally stated in the form of annual cost per inhabitant, a daily flow of sewage of 100 gallons for each inhabitant being assumed as the basis of the computation. The cost of chemicals has been calculated from the foregoing price per pound for the oxides. In regard to the prices used, the authors are of the opinion, after some correspondence with manufacturers and dealers, that the price of $10 per ton for copperas, as an average price for use in this country, is somewhat low, $15 being nearer correct. The most of the crude copperas of commerce consumed in the United States is a bye-product from rolling-mills. Much of it comes from the Cleveland Rolling Mill Co. and the Ferric Chemical & Color Co., of Worcester, Mass., which takes wastes from the Washburne & Moen wire shops.

Crude sulphate of alumina is worth at the present time, on board in New York, Boston, and Philadelphia, from $20 or under to $25 per ton, the exact price depending upon quality. The cost of sulphate of

alumina is largely increased by the process of refining. Manufacturers state that if a product with a little iron in it, say four per cent., could be used it could be produced and sold at a little less than a cent a pound. If there was a steady demand for the chemical in car load lots it seems probable that in time this price would be still further reduced. With ordinary sewage the iron in the alumina would certainly not be an objection and might be an advantage. As a matter of fact iron is used in the "alumino-ferric" process in connection with alumina.*

In regard to the prices used, Mr. Hazen remarks that considering the cheapness of the raw materials, it seems probable that the cost of both sulphate of alumina and ferric sulphate might be materially decreased from the prices given, in case there should be a considerable demand for them. Lime and copperas, Mr. Hazen remarks, have already a large sale, and could not probably be obtained at lower prices, by reason of increased consumption.

The authors' opinion, as indicated in the foregoing, is that for the present the prices which Mr. Hazen has used are, as an average for the whole country, somewhat low, although for points in the state of Massachusetts they are undoubtedly approximately right. For other localities they may be easily corrected by ascertaining the cost on board at the place of manufacture.

Detail of the Experiments.

In all, three series of experiments were made: the first, in a tank 45 feet long, 30 inches wide, and 10 to 12 inches deep, with a capacity of about 700 gallons. The chemicals in solution were added to the sewage as it flowed by gravity, through a trough, into the tank, where it was allowed to settle. In one experiment, on June 1st, when the tank was full, the sewage was allowed to overflow at the opposite end from that at which it entered, the sewage with the chemicals flowing in continuously. The relation of inflow to tank capacity was such that the average length of time for the sewage to settle in passing through the tank was 90 minutes. In all the other experiments of the first series the inflow of sewage was stopped when the tank was filled,

*See the trade pamphlet, Practical Sewage Purification, with a Description of the Alumino-ferric Process, Invented and Patented by Peter Spence & Sons, Manchester, England.

The alumino-ferric is prepared in soluble cakes, which may be placed in the sewage in cages of different heights so that the amount dissolved will vary with the volume of the sewage; or it may be dissolved in a separate tank of either sewage or water and so that the solution will be of any desired strength and the solution admitted to the precipitation tanks as desired. According to figures in W. Santo Crimp's Sewage Disposal Works (p. 217) alumino-ferric is composed of 14 per cent. of soluble alumina (equal to 46.68 per cent. of sulphate of alumina); 0.75 per cent. of perchloride of iron; 33.81 per cent. of sulphuric acid in combination with the above bases; and 51.44 per cent. of water.

and the time of settling reckoned from the time when the tank was full. A summary of the results of the first series is given in Table No. 44, in which the column of the cost of chemicals per year per inhabitant has been added by the authors.

TABLE No. 44.—SUMMARY OF RESULTS OF CHEMICAL TREATMENT IN LARGE TANK AT LAWRENCE.

Date.	Chemicals per 1,000,000 gallons.	Cost of chemicals per year per inhabitant.	Organic matter removed, per cent.		Settled, hours.
			Loss on ignition.	Albuminoid ammonia.	
May 1 ..	1,000 lbs. of lime	$0.16	32	62	20
" 3 ..	2,000 " "	0.33	38	30	3
" 7 ..	2,000 " "	0.33	56	52	4
" 9 ..	2,000 " "	0.33	57	43	4
" 14 ..	1,600 " "	0.27	41	25	27
" 16 ..	2,100 " "	0.35	18	32	20
Average..	1,800 " "	0.30	40	42	......
June 1 ..	500 lbs. of alum	0.23	13	35	1½
" 1 ..	500 " " and 800 pounds of lime	0.36	43	38	1½
" 18 ..	500 " " and 800 " "	0.36	20	26	1
" 14 ..	500 lbs. of copperas and 600 lbs. of lime	0.19	60	22	1

The first series, while approximating closely to precipitation in a sewage purification plant, did not prove satisfactory, by reason of not giving comparative results as with the same sample of sewage. A large number of analyses have shown that there is not only a great difference in the composition of the sewage on different days, but also between different portions of sewage required to fill the same tank. In order, therefore, to get results which were strictly comparable, it was decided to make parallel experiments on the same samples. To accomplish this, barrels were so set that they could be filled from one of the large measuring tanks at the station. The measuring tank was filled, thoroughly mixed, and while still being stirred, the barrels filled from it and chemicals added as desired. In order to show the effect of simple sedimentation, one barrel was left in each case to settle without chemicals. The barrels were 30 inches high and held about 50 gallons each. A computation was made of the amount of the precipitant per 1,000,000 gallons required for each barrel.

The chemicals were mixed in each barrel and the contents allowed to stand until thorough precipitation had taken place, after which a sample of the effluent was drawn from a tap about 10 inches above the bottom, the liquid first running freely for a minute, so that a sample fairly represented the contents of the barrel above the sludge. In this way a series of about 70 experiments were made in the months of May, June, and September, with the final one of the series on October 1, 1889.

Beginning October 2, 1889, a third series of experiments, much more

TABLE NO. 45.—SUMMARY OF MR. HAZEN'S SECOND SERIES OF EXPERIMENTS ON CHEMICAL TREATMENT AT LAWRENCE.

Chemicals per 1,000,000 gallons of sewage.	Cost of chemicals per inhabitant annually.	Number of experiments.	Per cent. loss on ignition removed.	Per cent. albuminoid ammonia removed.
Sewage after settling (sediment merely)	$0.00	10	30	26
Effluent with 700 lbs. of lime	0.11	5	39	33
Effluent with 500 lbs. of lime	0.23	2	27	40
Effluent with 500 lbs. alum and 700 lbs. lime	0.34	5	37	48
Effluent with 500 lbs. copperas	0.09	1	36	21
Effluent with 500 lbs. of copperas and 700 lbs. of lime	0.20	6	48	50
Effluent with 120 lbs. ferric oxide	0.13	2	64	33
Effluent with 120 lbs. of ferric oxide and 700 lbs. of lime.	0.24	3	57	51

elaborate than the previous ones, was made in order to determine more definitely the best proportion of the various chemicals and their respective merits. These experiments were also made in barrels, the same as already described for the second series. In the first and second series precipitation had been in some cases continued longer than one hour, but in the third the time of settling was taken uniformly at one hour. In regard to this Mr. Hazen says a slightly better result would be obtained by waiting longer before taking the samples; but a few experiments indicated only a slight difference between 1 and 4 hours' settling, and in comparative experiments on sewage the advantage of making the experiments and completing the analyses on the same day is very great. It was also thought that an hour's settling in a tank 30 inches deep may be equivalent to 2 or 3 hours' settling in a tank 6 feet deep.

EXPERIMENTS WITH LIME.

Before giving the detail of the third series of experiments, Mr. Hazen describes the method of the analyses of sewage which has been employed. In regard to precipitation with lime it is stated:

The quicklime of commerce does not have a constant composition. It has been thought best, for the purpose of these experiments, to take an arbitrary amount of calcium oxide in solution, as lime water, to represent a ton of lime, rather than weigh out lime for experiment. This method will give strictly comparable results, while, if the lime was weighed out, there would always be uncertainty as to the composition of the portion used, as different lumps of lime from the same barrel, and even different portions of the same lump, may differ widely from each other in composition. If pure calcium oxide is dissolved in distilled water at the rate of one ton per million gallons, it will have an acid number of alkalinity of 0.86; i.e., it will require 0.86 cubic centimetres of normal sulphuric acid, 49 grammes per litre, to neutralize 100 cubic centimetres. But quicklime only contains, on an average, perhaps 80 to 85 per cent. of uncombined calcium oxide, and a portion of this is difficultly soluble, so that it is impossible to make a lime water which represents the full theoretical strength of the lime. In a few experiments in dissolving lime in sewage, 10 to 15 per cent. of the lime proved to be not easily soluble. From these experiments I have assumed that lime will on the average yield 70 per cent. of its weight of calcium oxide in solution. This is believed to be a fair estimate,

which can be obtained in practice. This corresponds nearly to an acid number of 0.60 for one ton per million gallons, and I have taken that as a basis for computing the amount of lime used in each experiment. The lime is slaked with a large amount of sewage, and, after settling, the acid number is obtained by titration. From this is calculated the amount of lime water to be added to the sewage.

By treating sewage with a large excess of milk of lime the undissolved calcium hydrate in settling carries down the insoluble organic matter almost completely, and in a very short time.

On May 10 an experiment was made as follows: A weighed portion of lime was slaked in a barrel and the barrel filled with sewage. After settling for a few minutes the cleared liquid was drawn off and the barrel again filled with sewage. This was repeated until the lime was exhausted. In all 480 gallons of sewage were treated. The lime used was at the rate of 6,600 pounds per 1,000,000 gallons; 4.8 gallons of sludge were left, having 4 per cent. of solid matter. This process could not be used on a large scale owing to the amount of lime required and the excess of lime left in solution, which would slowly precipitate out on exposure to the air. The completeness with which the bacteria are removed or killed, and the large volume of liquid which can be treated in a small tank, might render it of use in some cases for disinfection. The results were as follows:

TABLE No. 46.—RESULTS OF PRECIPITATION WITH LARGE EXCESS OF LIME.

(Parts per 100,000.)

May 10, 1889.	Total solids.	Loss on ignition.	Fixed residue.	Free ammonia.	Albuminoid ammonia.	Chlorine.	Bacteria per cubic centimetre.
Original sewage	43.2	17.6	25.6	1.48	0.36	5.24	1,881,400
Filtered through paper	38.8	13.2	25.6	1.48	0.22	....	....
Effluent with lime after 5 minutes	113.4	11.8	101.6	1.48	0.18	5.35	12
Effluent after one hour	95.8	8.0	87.8	1.48	0.19	5.26	17
Effluent after 24 hours	93.4	10.2	83.2	1.37	0.18	5.31	5
Effluent from another sewage, 5 minutes	155.2	17.2	138.0	1.92	0.29	5.70	774
Sludge representing 100 times its volume of sewage	4,067.0	414.0	3,653.0	3.60	21.40	6.56	100

The action of smaller amounts of lime is quite different. Calcium carbonate is then formed with the carbonic acid of the sewage, and it is thus the carbonate instead of the hydrate which clarifies the sewage. Calcium carbonate is somewhat soluble in water or sewage containing carbonic acid. To obtain a precipitate it is necessary to add enough lime to combine with the greater part of the carbonic acid.

The report gives the details of four experiments with different amounts of lime. In each case seven barrels were filled from the same tank of sewage and varying amounts of lime added. From the tabulations and diagrams of the results it appears that, with increased amounts of lime, there is a regular improvement in the effluent, until the point is reached where the lime is equal to the carbonic acid; beyond this point the addition of a larger amount of lime does not usually remove any more organic matter. A further increase does, however, kill bacteria, as shown by the results in Table No. 46. A quantity of lime, equal or nearly equal to the carbonic acid, may therefore be taken as the practicable limit of efficiency in a simple lime treatment. What may be accomplished by such a treatment is fully indicated in Table No. 47.

TABLE NO. 47.—RESULTS OF PRECIPITATION WHEN THE LIME USED WAS EQUAL OR NEARLY EQUAL TO THE CARBONIC ACID.

	Oct. 2.	Oct. 4.	Oct. 8.	Oct. 9.	Average.
Amount of lime used, pounds	1,500	1,600	1,600	1,800	1,625
Albuminoid ammonia of sewage	0.85	0.72	0.56	0.90	0.76 parts per 100,000
Remaining after filtering through paper	47.	53.	50.	55.	51. per cent.
Remaining after precipitation	34.	44.	44.	44.	41. per cent.
Loss on ignition of sewage	24.2	23.6	22.0	44.8	28.6 parts.
Remaining after filtering through paper	50.	61.	60.	70.	61. per cent.
Remaining after precipitation	50.	56.	49.	50.	51. per cent.
Turbidity of sewage	1.00	0.50	0.50	0.60	0.65 parts.
Remaining after precipitation	23.	26.	28.	20.	24. per cent.
Bacteria of sewage	196,000	1,572,000	....	1,364,000	1,044,000
Remaining after precipitation	6.2	0.73	....	0.55	2.5 per cent.

This table shows that by the use of an amount of lime corresponding to the carbonic acid in the sewage, all of the suspended organic matter has been removed, together with 20 per cent. of the soluble albuminoid ammonia, 15 per cent. of the soluble loss on ignition, 97 per cent. of the bacteria, 76 per cent. of the turbidity, at a cost for chemicals of $7.31 per million gallons, or 27 cents per inhabitant annually.

LIME AND COPPERAS.

The second series of experiments had indicated that it was necessary to add lime with copperas, in order to get the best result from a copperas treatment. Additional experiments were carried out in the third series to ascertain how much lime is required, the effect of different amounts of copperas, and whether the sewage shall first be mixed with the lime or with the copperas.

The experiments with copperas show clearly that when copperas is added to sewage alone, the result is on the whole no better than may be obtained from simple sedimentation. In order to produce precipitation it is necessary to add lime enough to combine with the excess of the carbonic acid over the amount required to form bi-carbonates and to combine with the sulphuric acid of the copperas. When the proper amount of lime is added, the acid number with phenolphthalein will be zero. To insure rapid action, lime should be added slightly in excess, but no better result will be obtained when more than a slight excess of lime is used. If much less than the proper quantity is used, the iron will not be precipitated, and the result will be the same as in simple sedimentation without chemicals.

The test with phenolphthalein shows instantly whether enough lime has been added, and it can be used by any one. If enough lime is present in the sewage, to which a few drops of a solution of phenol-

phthalein in alcohol is added, it will be turned blood-red, while, if the amount is too small, the sewage will remain uncolored.

Mr. Hazen states that this reaction is equally useful in the precipitation by lime of acid sewage containing iron from manufacturing wastes. In this case, the copperas is already carried by the sewage, and the addition of lime is required to neutralize the acid, thus precipitating the iron and rendering it available. An elegant application of this principle has been made in the chemical treatment of the sewage of the city of Worcester, which is an acid sewage containing large quantities of iron manufacturing wastes. For further discussion of this part of the subject, the reader is referred to Chapter XXVII. descriptive of the Worcester disposal works.

A series of experiments were made for the purpose of determining the effect of different amounts of copperas when used with the proper amount of lime, as indicated by the phenolphthalein reaction. The results, with amounts of lime best adjusted to the given amount of copperas, are indicated in Tables 48 and 49.

Summarizing the results of these two tables, it is found that with 500 pounds of copperas per 1,000,000 gallons of sewage, and an amount of lime best adjusted to the copperas, there will be removed all of the suspended organic matter, 13 per cent. of the soluble albuminoid ammonia, 14 per cent. of the soluble loss on ignition, 65 per cent. of the turbidity, and 88 per cent. of the bacteria, with a cost for chemicals of $5.44 per million gallons, or 20 cents annually per inhabitant.

With 1,000 pounds of copperas per 1,000,000 gallons of sewage, and an amount of lime best adjusted thereto, there was removed all of the suspended organic matter, 39 per cent. of the soluble albuminoid ammonia, 39 per cent. of the soluble loss on ignition, 75 per cent. of

TABLE NO. 48.—RESULTS OF TREATMENT OF SEWAGE WITH ABOUT 500 POUNDS OF COPPERAS FOR 1,000,000 GALLONS, AND AN AMOUNT OF LIME BEST ADJUSTED TO THE COPPERAS.

	Oct. 11.	Oct. 18.	Oct. 22.	Average.
Amount of copperas used	500	400	500	467 pounds.
Amount of lime used	800	630	650	693 pounds.
Albuminoid ammonia, sewage	0.79	0.67	0.66	0.71 parts per 100,000
Remaining after filtering through paper	54.	60.	68.	61. per cent.
Remaining after precipitation	39.	60.	60.	53. per cent.
Loss on ignition of sewage	25.8	21.2	23.8	23.6 parts.
Remaining after filtering through paper	67.	75.	71.	71. per cent.
Remaining after precipitation	57.	73.	53.	61. per cent.
Turbidity of sewage	0.50	0.50	0.60	0.53
Remaining after precipitation	30.	40.	36.	35. per cent.
Bacteria of sewage	176,000	322,400	507,800	335,000
Remaining after precipitation	32.	2.	3.	12. per cent.

Table No. 49.—Results of Treatment of Sewage with 1,000 Pounds of Copperas per 1,000,000 Gallons, and an Amount of Lime best adjusted to the Copperas.

	Oct. 16.	Oct. 18.	Oct. 22.	Average.
Amount of copperas used	1,000	1,000	1,000	1,000 pounds.
Amount of lime used	800	800	800	800 pounds.
Albuminoid ammonia of sewage	0.94	0.67	0.66	0.76 parts per 100,000
Remaining after filtering through paper	70.	60.	68.	66. per cent.
Remaining after precipitation	35.	43.	41.	40. per cent.
Loss on ignition, sewage	29.2	21.2	23.8	24.7 parts.
Remaining after filtering through paper	77.	75.	71.	74. per cent.
Remaining after precipitation	30.	57.	47.	45. per cent.
Turbidity of sewage	0.65	0.50	0.60	0.58 parts.
Remaining after precipitation	18.	30.	28.	25. per cent.
Bacteria of sewage	....	322,400	507,800	415,000
Remaining after precipitation	....	2.	2.	2. per cent.

the turbidity, and 98 per cent. of the bacteria, with a cost for chemicals of $8.60 per million gallons, or 31 cents per inhabitant annually.

Ferric Sulphate.

Mr. Hazen states that ferric salts have the advantage over ferrous salts, in that ferric hydroxide is more readily precipitated and more completely insoluble than ferrous hydroxide.

A number of experiments were made to determine whether it was necessary to add lime in order to obtain the best results with ferric salts, and, if so, how much should be used; also to ascertain the effect of different amounts of ferric salts when used alone.

As already stated, the ferric salt used for the experiments was ferric sulphate, but Mr. Hazen says there is every reason to suppose that exactly the same results would be obtained with ferric chloride containing an equal amount of iron.

The experiments, with a combination treatment of lime and ferric sulphate, show that the influence of the lime is very small. With an amount of ferric sulphate equivalent to 200 pounds of ferric oxide, the result was slightly better, when 800 pounds of lime were used. With the equivalent of 400 pounds of ferric oxide, in combination (1) with 500 pounds of lime and (2) with 1,000 pounds of lime per 1,000,000 gallons treated, the results show that the lime had almost no influence. With 300 pounds of ferric oxide, no better result was obtained by mixing the sewage with 1,000 pounds of lime *before* adding the ferric sulphate; when the lime was added to the sewage *after* the ferric sulphate, the result was not quite so good as when no lime was used.

The conclusion is, therefore, that the best results will be obtained from the ferric sulphate when used alone.

Table No. 50.—Results of Treatment of Sewage with Ferric Sulphate.

	Nov. 5.	Nov. 6.	Nov. 6.	Nov. 5.	Nov. 6.
Ferric oxide used as ferric sulphate	200	200	300	400	400 pounds.
Albuminoid ammonia, sewage	0.57	0.52	0.52	0.57	0.52 parts per 100,000
Remaining after filtering through paper	56.	69.	69.	56.	69. per cent.
Remaining after precipitation	45.	59.	36.	33.	33. per cent.
Loss on ignition, sewage	22.8	22.4	22.4	22.8	22.4 parts.
Remaining after filtering through paper	70.	76.	76.	70.	76. per cent.
Remaining after precipitation	36.	42.	13.	18.	13. per cent.
Bacteria in sewage per cubic centimetre	218,960	1,398,600	1,398,600	218,960	1,398,600
Remaining after precipitation	14.	14.	9.	3.	5 per cent.
Suspended organic matter removed	All.	All.	All.	All.	All.
Soluble albuminoid ammonia removed	20.	15.	48.	41.	52. per cent.
Soluble loss on ignition removed	7.	0.	21.	50.	43. per cent.
Turbidity removed	64.	58.	87.	82.	87. per cent.
Bacteria removed	86.	86.	91.	97.	95. per cent.
Cost per inhabitant annually for chemicals	22 cents.	22 cents.	33 cents.	44 cents.	44 cents.

Table No. 50 gives the results of the experiments in which only ferric sulphate was used.

Aluminum Sulphate.

The next series of experiments were with aluminum sulphate, the action of which upon sewage is analogous to the ferric sulphate. Mr. Hazen remarks that there is every reason to suppose that aluminum chloride containing the same amount of alumina will give exactly the same results as the sulphate.

The first experiments with this salt were made for the purpose of determining (1) whether lime could be used advantageously with sul-

Table No. 51.—Results of Treatment of Sewage with Aluminum Sulphate.

	Nov. 1.	Oct. 29.	Nov. 1.	Average.
Alum used per 1,000,000 gallons, pounds	500	1,000	1,000	With 1,000 pounds.
Albuminoid ammonia, sewage	0.45	0.67	0.45	0.56 parts per 100,000
Remaining after filtering through paper	71.	58.	71.	64. per cent.
Remaining after precipitation	64.	24.	44.	34. per cent.
Loss on ignition, sewage	27.	30.4	27.0	28.7 parts.
Remaining after filtering through paper	50.	56.	50.	53. per cent.
Remaining after precipitation	52.	29.	66.	47. per cent.
Turbidity of sewage	0.40	2.00	0.40	1.20
Remaining after precipitation	32.	7.	27.	17. per cent.
Bacteria in sewage, per cubic centimetre	361,328	835,200	361,328	598,264
Remaining after precipitation	3.	1.	17.	9. per cent.
Suspended organic matter removed	Nearly all.	All.	Nearly all.	
Soluble albuminoid ammonia removed	10.	59.	38.	47. per cent.
Soluble loss on ignition removed	0.	48.	0.	24. per cent.
Turbidity removed	68.	93.	73.	83. per cent.
Bacteria removed	97.	99.	83.	91. per cent.
Cost of chemicals per 1,000,000 gallons	$6.25	....	....	$12.50
Cost for chemicals per inhabitant annually	0.23	....	....	0.45

phate of alumina; and (2) the effect of different amounts of the same. The results indicate that, as with ferric sulphate, lime has little or no effect. The precipitation is a little more rapid when lime is used, but the short gain in time will hardly compensate for the extra cost. Table No. 51 gives the results of three experiments, in which sulphate of alumina only was used as a precipitant.

The three series of experiments, outlined in the foregoing, indicate the following:

(1) That with a given quantity of sewage, a certain definite amount of lime gives as good or better results than either more or less.

(2) That in general, the more copperas, ferric sulphate, or aluminum sulphate used, the better the result.

(3) That ferric sulphate and aluminum sulphate usually require no lime for completing precipitation.

(4) That with copperas a definite amount of lime must be used.

Results With Different Amounts of Chemicals but of Equal Value.

In order to compare the results obtained with the best amount of lime with equal value of the other chemicals, when used under the most favorable conditions on the same sample of sewage, two additional experiments were made, the second being, presumably, for the purpose of checking the first. The results of the first set are given in Table No. 52. Table No. 53 gives the per cent. of soluble organic matter removed by chemicals of equal value, as determined by the two final sets of experiments.

Taking the percentage of albuminoid ammonia removed to repre-

Table No. 52.—Results of Treatment of Sewage with Equal Values of Different Chemicals (Nov. 22, 1889).

	Cost of chemicals.*	Turbidity.	Total solids.	Loss on ignition.	Fixed residue.	Free ammonia.	Albuminoid ammonia.	Chlorine.	Bacteria per cubic centimetre.	Yeast cells per cubic centimetre.
Original sewage	....	0.40	43.0	18.0	25.0	1.25	0.40	4.86	25,840	20,700
Filtered through paper	....	....	34.8	11.2	23.6	1.25	0.26	....	....	....
After settling 1 hour	....	0.30	38.8	13.6	25.2	1.25	0.28	4.82	10,920	16,700
Effluent with 1,800 pounds of lime per 1,000,000 gallons of sewage	$0.30	0.08	45.6	10.2	35.4	1.25	0.19	4.83	1,911	1,650
Effluent with 1,000 pounds of copperas and 700 pounds of lime	0.30	0.12	46.4	9.2	37.2	1.25	0.17	4.80	16,044	400
Effluent with 270 pounds of ferric oxide	0.30	0.08	38.0	8.0	30.0	1.25	0.18	4.92	2,047	1,000
Effluent with 650 pounds of alum	0.30	0.10	34.4	8.0	26.4	1.50	0.19	4.88	2,475	3,700
Effluent with 360 pounds of ferric oxide	0.40	0.07	37.6	5.8	31.8	1.25	0.15	4.96	1,980	1,000
Effluent with 870 pounds of alum	0.40	0.09	38.2	9.6	28.6	1.25	0.19	4.81	1,800	2,200

* Per inhabitant annually.

TABLE NO. 53.—PER CENT. OF SOLUBLE ORGANIC MATTER REMOVED BY CHEMICALS OF EQUAL VALUE, ETC.

Yearly cost.		Thirty cents.				Forty cents.	
Chemicals used.		Lime.	Copperas and lime.	Ferric oxide.	Sulphate of aluminum.	Ferric oxide.	Sulphate of aluminum.
Soluble albuminoid ammonia removed	Nov. 22.	27	35	31	27	42	27
	Nov. 26.	17	24	34	14	41	31
	Average.	22	29	32	20	41	29
Soluble loss on ignition removed......	Nov. 22.	9	18	29	29	48	14
	Nov. 26.	0	24	26	30	41	26
	Average.	4	21	28	30	45	20
Turbidity removed	Nov. 22.	80	70	80	75	83	78
	Nov. 26.	74	70	82	78	82	76
	Average.	77	70	81	77	83	77
Bacteria removed, Nov. 22......................		93	38	92	91	93	93
Yeast removed, Nov. 22.........................		92	98	95	82	95	90
Amount of chemicals per 1,000,000 gallons in lbs.		1,800	1,000 and 700	270	650	360	870
Cost of chemicals per 1,000,000 gallons treated...		$8.13.				$10.85.	

sent organic matter, it is shown that in addition to all suspended matter, the following amounts of soluble organic matter have been removed:

With lime costing 30 cents per inhabitant annually.................. 22 per cent.
With copperas and lime costing 30 cents............................ 29 per cent.
With ferric sulphate costing 30 cents .... 32 per cent.
With aluminum sulphate costing 30 cents............................ 20 per cent.
With ferric sulphate costing 40 cents.............................. 41 per cent.
With aluminum sulphate costing 40 cents............................ 29 per cent.
With lime costing 27 cents per inhabitant, annually.................. 20 per cent.
With copperas and lime costing 20 cents............................ 13 per cent.
With copperas and lime costing 31 cents............................ 39 per cent.
With ferric sulphate costing 22 cents.............................. 17 per cent.
With ferric sulphate costing 33 cents.... .... 48 per cent.
With ferric sulphate costing 44 cents.............................. 46 per cent.
With aluminum sulphate costing 23 cents............................ 10 per cent.
With aluminum sulphate costing 45 cents............................ 47 per cent.

DEDUCTIONS.

The following conclusions may be drawn from Mr. Hazen's experiments :

(1) The first series in large tanks (Table No. 44) made between May 1, and June 14, inclusive, may be considered as approximating more nearly to the actual conditions at sewage disposal works in operation than any of the others ; and the variation in the results are such as may be fairly expected from day to day due to changes in the composition of the sewage. The results, however, are not comparable

one with another by reason of using samples of varying composition taken on different days.

(2) Mr. Hazen does not consider the second series in barrels as reliable as the latter ones, by reason of some of the anaylses not being made until the day following the experiment. He therefore considers it probable that changes had occurred which affect the results.

(3) It may be said of all the experiments in barrels that (*a*) the quantity treated was rather small; tanks holding from 300 to 600 gallons would have been preferable, although the use of such would have required more time and additional apparatus, in the way of special appliances for mixing; and (*b*) that probably by reason of the small volume experimented upon the mixing was more thorough than usually occurs in practice. To obtain the same results on sewage of the same composition in actual practice will therefore necessitate the use of amounts in addition to the quantities indicated by the experiments, of perhaps 5 to 10 per cent.

(4) With lime largely in excess, as in the experiment of May 10, sewage can be treated on a small scale in such manner as to remove very nearly all the bacteria, the result being that with an original sewage containing 1,881,400 bacteria per cubic centimetre, the number found in the effluent of 5 minutes time was only 12; after 1 hour 17; and at the end of 24 hours 5. This process, however, could not be used on a large scale, owing to the large amount of lime required and the excess of lime left in solution, which would slowly precipitate out on exposure to the air.

(5) The best practical results with lime were obtained when the amount used was equal or nearly equal to the carbonic acid of the sewage. To produce this condition a definite quantity is required for a given sewage.

(6) The use of copperas alone is without much useful effect in the treatment of an ordinary sewage; the result being very little better than may be obtained by simple sedimentation. It is necessary to add enough lime, when copperas is used, to combine with the excess of carbonic acid over what is required to form bicarbonates, and to combine with the acid of the copperas, as the necessary conditions for precipitation. In general terms we may say that with a lime and copperas treatment there is a definite amount of lime that will give the best results.

(7) In using lime and copperas, the lime should be added first.

(8) For a given sewage treated with lime and copperas, the proper proportion of each should be determined by experiment. Up to one-half ton per 1,000,000 gallons, using in each case a suitable amount of lime, the more copperas used the better the result; beyond that limit the improvement is not commensurate with the cost.

(9) Other things being equal, ferric salts are preferable to ferrous salts by reason of quicker action and more insoluble precipitate.

(10) Lime is of almost no value for use with ferric sulphate, especially when treating a sewage which is already alkaline.

(11) Within limits, we may say the more of either ferrous or ferric sulphate used the better the result.

(12) For the sewage experimented upon, the use of lime with sulphate of alumina is of very little effect over what may be accomplished by the use of the alumina alone. The chief effect of the lime is to increase somewhat the rapidity of action, but the gain in time hardly compensates for the increased cost.

(13) The results in Tables 52 and 53 are probably the safest for comparison, subject to the limitations indicated in (3).

(14) The removal of bacteria is due partly to the mechanical action of the flocculent precipitates in which they are entangled and carried down, and partly to the action of the reagent as a germicide; but even the best of the various chemical treatments leave a relatively large number of bacteria in the effluent, together with such quantities of organic matter as may lead in a short time to the development of as many as were present in the original sewage. If any so left are disease germs the effluent may be nearly as dangerous to public health as the original sewage.

(15) The microscopical determination of the yeast may be considered a useful method of ascertaining whether or not the suspended organic matter is really all removed.

(16) The effluents from treatment with iron salts are slightly colored, which, however, Mr. Hazen does not consider an objection to the treatment.

(17) The practical difficulties of working the lime process renders the results in general inferior to those which may be obtained at the same cost in other ways.

(18) Copperas and lime treatment is difficult in practice owing to the necessity for adjusting the quantity of lime, although when such adjustment is properly made a good result is obtained.

(19) Ferrous hydroxide is more soluble than ferric hydroxide, from which results a larger amount of iron in the effluent from copperas treatment than from a ferric salt.

(20) The advantage of both ferric sulphate and aluminum sulphate is that their addition in concentrated solution can be accurately controlled without reference to the adjustment of any chemical to the sewage.

(21) The results with ferric sulphate have been on the whole more satisfactory than those with aluminum sulphate.

(22) By reason of (*a*) variations in the composition of sewage at dif-

ferent places; and (*b*) changes in prices of the reagents it is impossible to say that one treatment is universally better than another.

(23) An acid sewage containing iron may be properly treated with lime.

(24) By the use of a proper amount of either an iron or aluminum salt, from one-half to two-thirds of the organic matter of sewage may be removed by chemical precipitation. With the process carried out in detail the effluent can be discharged into a running stream without producing a nuisance.

(25) The incompleteness of the purification in comparison with the cost of the process will be likely to confine the application of chemical purification to narrow limits.

(26) There is nothing in these experiments to indicate that the effluents from chemical treatment are fit to drink.

Purification of Sewage by Aeration.

In Table No. 53A are given the results of a series of experiments on the treatment of sewage by aëration made for the Metropolitan Board of Works (London), by Dr. A. Dupré and W. J. Dibdin. In each case 1,000 gallons of raw sewage was first treated with 5 grains per gallon of lime as lime-water, and the same amount of copperas. Series (1) and (2) show the means for 10 samples of raw sewage and the effluents from the same. Series (3) shows (2) corrected for the lime-water, of which 72 gallons was added in each case. Series

Table No. 53A.—Results of Treatment of Sewage with Lime and Copperas, Followed by Aëration of Effluent.

(Grains per Imperial gallon.)

Serial number.	Description of sample.	Number of experiments of which mean is taken.	Dissolved solids.			Ammonia.		Chlorine.	Suspended matter.			Oxygen absorbed.	
			Total.	Mineral.	Organic.	Free.	Albuminoid.		Total.	Mineral.	Organic.	5 minutes at 80° F.	4 hours at 80° F.
1	Raw sewage	10	63.29	42.40	21.07	3.942	0.5205	6.40	11.36	4.84	6.52	0.853	3.016
2	Effluent from (1)	10	48.22	34.34	13.88	3.549	0.3847	6.32	6.50	5.38	1.12	0.587	2.274
3	Corrected effluent*	10	51.68	36.80	14.88	3.803	0.4122	6.77	6.96	5.76	1.22	0.629	2.300
4	Effluent before aëration	8	54.78	34.74	20.04	4.575	0.5408	6.64	1.28	0.89	0.39	0.710	2.437
5	After aëration (4)	8	53.62	31.31	22.31	3.250	0.5480	6.80	3.35	2.04	1.31	0.621	2.292

* In these experiments 1,000 imperial gallons were used in each case. This quantity of sewage was diluted with 72 gallons of clear lime-water added to each 1,000 gallons of sewage; therefore, to compare the effluent with the sewage, it is necessary to correct the results of the analyses for that degree of dilution with clear water, thus:— $\frac{1,000}{1,072} = 0.933$; hence $\frac{\text{result obtained}}{0.933}$ = corrected result. In this way the results of (2) have been corrected, making (3).

(4) is the mean of 8 effluents which were treated by aëration with the result indicated in (5). In studying the results it must be borne in mind that (4) and (5) are different series from (2) and (3).*

By comparing series 4 and 5 of Table 53A it will be seen that aëration had but little effect upon the sewage. The same conclusion was reached in some experiments with diluted sewage by Mr. S. K. Hine.† Dr. T. M. Drown in experiments with natural waters and with water to which a small amount of sewage had been added, concludes that "The oxidation of organic matter in water is not hastened by vigorous agitation with air or by air under pressure."‡

In considering the significance of these new views we must not forget that the presence of oxygen is still imperative in order to secure the operation of the living agents. Moreover when large quantities of organic matter are present it is still permissible to assume some degree of direct oxidation, and it is in this latter view that we have discussed the matter in the beginning of Chapter V.

Chemical Precipitation by the Use of Manganate of Soda and Nitre.

As we have seen, the tendency of the effluents from chemical processes, especially those dependent upon lime, is on the whole toward putrefaction, even when considerably diluted after discharge into running streams. This result is due primarily to a deficient supply of oxygen, whereby the microbes of nitrification may develop in sufficient quantity to complete the resolution of the organic matter still remaining in the effluent. If, then, the chemical purification is effected by some reagent which leaves a considerable quantity of oxygen in the effluent, we may expect an improvement in this particular.

* Table No. 53A is derived from Appendix D H of the Report of the Roy. Com. on Met. Sew. Dischg., p. 201.

† Recounted in a paper entitled "Note on the Direct Oxidation of Organic Matter in Water," by Professor W. P. Mason and S. K. Hine, Jour. Am. Chem. Soc., vol. xiv., no. 7. The experiments were made by Mr. Hine and the results presented as a graduating thesis at the Rensselaer Polytechnic Institute in June, 1892. Varying proportions of sewage and water were placed in a tin can or in a glass stoppered bottle, mostly in the latter, the receptacle being not over half full. The can or bottle was then fastened to the connecting rod of a horizontal steam-engine of 10-in. stroke and the engine run at 75 revolutions per minute, so that in an hour the receptacle was shaken 9,000 times and travelled about 1.25 miles. The samples were shaken from 13 to 60 hours and 24 samples were tried, analyses being made before and after shaking. The paper states that:

An examination of the results shows that the amount of oxidation which took place during the agitation of the water was very trifling, a finding entirely in accordance with Professor Leeds' observations of the water of the Niagara river before and after passing Niagara Falls. Direct oxidation does not seem to be a factor of any considerable importance in the purification of polluted water.

‡ "The Effect of the Aëration of Natural Waters," by Dr. Thomas M. Drown, chemist of the Board. Rept. Mass. St. Bd. of Health for 1891. Also in Jour. New Eng. W. Wks. Assn., Dec., 1892, and Eng. News, vol. xxviii, pp. 183–4 (Aug. 25, 1892).

Working in this direction Mr. W. E. Adeney, curator in the Royal University of Ireland, and Mr. W. Kaye Parry, of Dublin, have experimented on the use of manganate of soda and nitre. Their results are given in two papers read before the British Institute of Public Health at the 1892 meeting in Dublin.

The theory upon which they have proceeded is that when nitre is added to sewage containing aërobian forms of bacteria it is readily decomposed into nitrogen, oxygen, nitric oxide, and potash, and thus furnishes the oxygen necessary for their growth. To secure such results the sewage is first cleared of suspended solids by a process of sedimentation, after which it is treated with from two to five grains per gallon of manganate of soda. This reagent effects the oxidation of a considerable portion of the organic matter, and becoming converted into the brown oxide of manganese, falls to the bottom, carrying with it a portion of the lighter particles which have not been removed by the previous sedimentation. The sewage is now partially purified, and it is claimed that the addition of two to three grains to the gallon of the nitre at this stage so stimulates the growth of aërobian forms as to either quickly complete the purification, or so far complete it that the effluent may be innocuously discharged into running streams.

As to the time required for the completion of the process, it is believed that less than 24 hours will be sufficient, although at Dundrum Lunatic Asylum (Ireland), where the process is now in operation, the time consumed is about 25 hours, that being the length of time required to completely fill the tank space which has been provided. The effluent after this time is stated to be clear and bright and absolutely non-putrefactive.

In regard to the cost of the process, it is stated that all the manganese is recovered and can be reconverted at about half the original cost. The length of time required for the completion of the process will, however, lead, with allowances for contingencies, to a tank capacity somewhat in excess of the daily flow; and this fact will be likely to limit the application of the process, whatever its other merits may be, on account of expense.*

* For more extended account see Purification of Sewage by Microbes. Eng. and Bldg Rec., vol. xxvii, p. 380 (Nov. 12, 1892).

CHAPTER XII.

BROAD IRRIGATION.

Special Applications of Broad Irrigation in the United States.

The opinion has been expressed frequently that broad irrigation will not, by reason of the large amount of labor required and the relatively high price of the same, be generally used in this country. There will, however, be some exceptions to this in especially favorable localities, and in the case of such public institutions as asylums, alms houses, and reformatories, where labor may be furnished by the inmates without expense, or in the West, where all available water is needed for application to crops to make up for a deficient rainfall, such use, combined with a desire for sewage purification, being described at length in Chapter XLIV., on The Use of Sewage for Irrigation in the West.

Broad irrigation is specially adapted for the use of hospitals for the treatment of the harmless insane, all the authorities now agreeing that light out-door employment is the best remedy for such cases that can be applied. Some account of broad irrigation is therefore imperative in a volume professing to treat of sewage disposal with reference to the special conditions obtaining in the United States. Many phases of the question, which have been thoroughly treated elsewhere, will be left untouched, the space assigned to the subject being mostly taken up with a discussion of some points which the authors deem of relatively more importance for American readers. Such short discussion of irrigation as is made will be with reference to the utilization of sewage only.

Preparation of Land—Pipe and Hydrant System of Distribution.

In broad sewage irrigation areas of land are suitably prepared for the distribution of sewage with reference to utilizing the manurial ingredients in raising crops. For this purpose a number of methods of distribution of sewage and preparation of irrigated area are employed which we may describe a little in detail, the pipe and jet mode of dis-

tributing sewage first claiming our attention.* In this method a series of pipes is laid according to a system depending upon the topography. At such points as will permit of conveniently reaching all parts of the field stand-pipes or hydrants are placed, fitted with the usual coupling for connecting hose. The sewage is forced through these

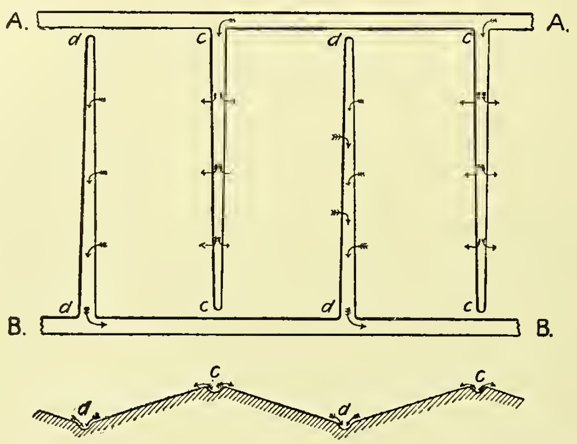


FIG. 12.—PLAN AND SECTION OF RIDGE AND FURROW SYSTEM.

either by steam power or by gravitation and is distributed to the surface of the field by means of the hose, and when necessary by the use of a jet—the rapidity of the distribution depending upon the size of mains and amount of power applied.

With gravitation the power will of course be fixed by the height of the receiving tank, into which the sewage is first collected, above the area to be irrigated ; but in a pumping system the power can be varied the same as in any other application of pumping. The detail of arranging either system will readily present itself to any skilful engineer with all the facts before him. In England a large number of pipe distribution systems are to be met with, while in this country the distribution at the Pullman, Illinois, sewage farm is effected in the same manner. (See Chapter XXX.) As a very complete system of this kind the reader is referred to the description of a sewage farm at Rugby, England, laid out on this system, as given by Mr. R. Scott Burn.†

In systems of gravity distribution by carriers there are two methods

* See Outlines of Modern Farming, Part V., Utilizing of Town Sewage, Irrigation, etc. By Robert Scott Burn, 6th ed., 1888.

† See also Report on the Means of Deodorizing and Utilizing the Sewage of Towns. By Henry Austin, C. E. (1857).

in common use, namely, (1) the ridge and furrow or bed-work system, shown by Figs. 12 and 13; and (2) the catchwork system, shown by Fig. 14. Which of these to use in any given case will depend upon the topographical features of the area to be irrigated.

The ridge and furrow system is specially applicable to level or nearly level land; while the catchwork system will be used preferably in irregular, steep, or hilly ground.

Ridge and Furrow System.

In ridge and furrow work the land is laid out in a series of beds along the top of which the irrigating channels are led, and from which the water flows over the sloping sides. The ridges are laid out in couples, with slopes varying from 1 in 50 to 1 in 150. The amount of slope to be given in any particular case is a matter of judgment, in the decision of which the controlling factor is porousness of the ground to be irrigated. Common dimensions of the bed are a total breadth of from 30 to 40 feet, that is a breadth of slope on each side of the ridge of from 15 to 20 feet, although in exceptional cases the breadth may by made considerably greater. The land may be underdrained in accordance with the rules for underdraining in ordinary farming, the same rules applying in both cases.* In deciding whether or not to fully underdrain any given area, it may be remembered that the porousness of the soil is always increased by drainage. The

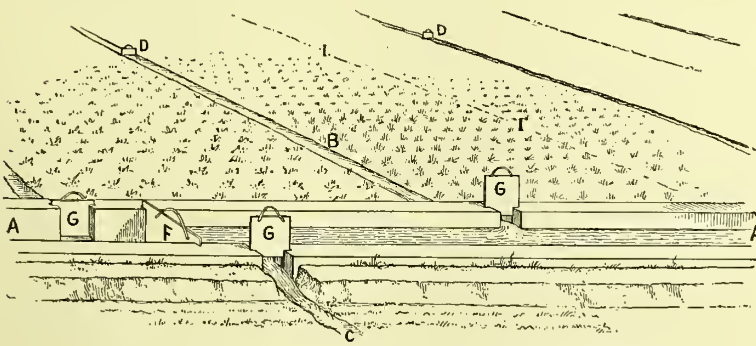


Fig. 13.—Ridge and Furrow Beds with Cropping.

length of the beds may be anywhere from 100 to 200 feet, according to circumstances. The distribution channels along the ridge should be executed with care in order that when full the sewage may flow in a thin film over the edge at both sides and so on in a broad sheet

* For rules of underdraining see (1) Waring's Draining for Profit and Draining for Health; and (2) French's Farm Drainage.

over the whole field. At the foot of the slopes the furrow receives whatever water has not been absorbed in the passage over the bed and conducts it away to another and lower series of beds or to the outfall, as the case may be ; though ordinarily the surplus water should pass over several areas, especially if constructed with about the dimensions given in the foregoing. In order to insure thorough removal of the water at the foot of the slopes, and to prevent the land there becoming water-logged, the furrow should be made of about the same size as the feeder on the ridge and with enough fall to produce quick drainage. Fig. 12 shows in plan and section the arrangement

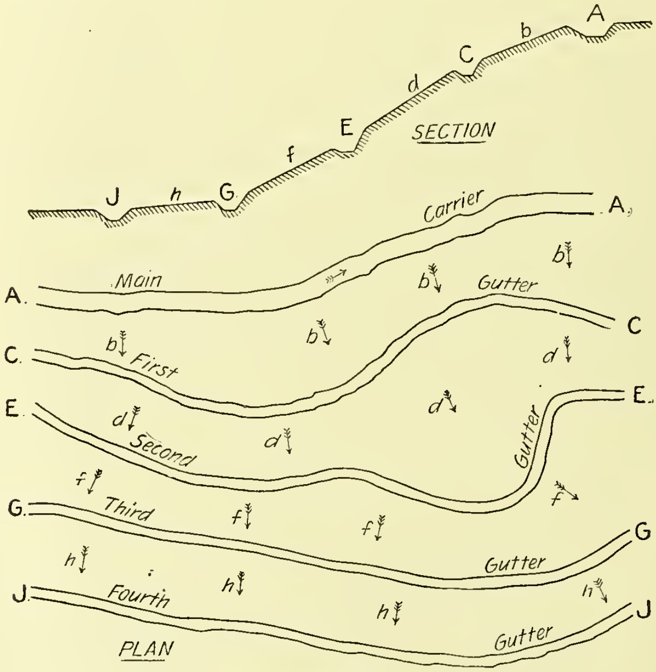


FIG. 14.—CATCHWORK SYSTEM OF IRRIGATION.

of a ridge and furrow system of irrigation. Fig. 13 is a general view of a ridge and furrow system in crops.

CATCHWORK SYSTEM.

In the catchwork system, which as stated is specially adapted to steep and irregular land, the liquid is delivered at the highest point of the area, the same as with ridge and furrow. A main carrier is led along the highest contour, and the irrigation water caused to overflow the edge by damming at various places. At some distance lower

down a catch-gutter is formed also on the contour, into which the unabsorbed overflow of the main carrier is caught as it flows downward over the surface. The damming at suitable intervals of the first catch-gutter causes it again to overflow to a second, and so on down to the lowest contour of the area irrigated. The detail of this operation may be illustrated by Fig. 14, in which a catchwork system is shown in section by the upper portion, and in plan by the lower. Let A represent the main carrier at the highest point of the area to be irrigated, with just fall enough to enable the stream to flow gently from left to right. The relative position of the gutters on the down-hill side are clearly shown by the plan and elevation. The damming of AA at various points will cause the water to flow over the edge, down the slope b to the gutter CC; and so on until the lower gutter JJ is finally reached. The fall of the main carrier should be about 2 inches to 100 feet, its breadth from 18 to 24 inches and its depth from 8 to 10 inches. The gutters are made level throughout their length, and on very irregular ground a considerable degree of skill is required in order to secure such arrangement as will insure that all parts of the area receive their due proportion of water.

As a further refinement of this system of irrigation in the way of securing a more uniform distribution of the water over the area, immediately below the main carrier a series of tapering carriers are cut in the line of the greatest descent, as indicated by the arrows on the plan at Fig. 14. These may also be continued below the gutters when necessary to assist the distribution on very irregular ground.

Cost of Distribution Systems.

In reference to the relative cost of the three systems of irrigation which have been described, it may be remarked that distribution by pipes will be fairly economical. In England a number of such systems have been carried out with the distribution pipes of iron, but at Pullman vitrified tile pipes have been used with good results.* The advantage of pipe distribution is that it admits, when the hydrants are placed at short intervals, of a more thorough control of the amount of sewage distributed to any given portion of the area than can be obtained by any other method. No general estimate of the cost of distribution by this system per acre can be given, because the items will vary greatly for every different case, but as the use of it does not involve any unknown conditions, an accurate estimate can be easily

* See Paper, The Pullman Sewerage, Jour. of the Assn. of Eng. Socs., vol. i. (June, 1882), p. 311. By Benezette Williams, C. E.

The most of the pipe distribution systems in England have been made rather expensive by the use of cast-iron distribution mains, etc., the cost reaching frequently as high as $40 to $60 per

prepared in each case after a topographical map of the area to be irrigated has been made.

The original cost of preparation of ridge and furrow work in England has been from $100 to $250 per acre, English prices, which, carried into American prices for labor, would be approximately from $175 to $450 per acre. The latter figure has, however, included the cost of expensive main carriers of masonry or iron, and some other items which are not considered essential to the success of sewage irrigation at the present day. It must be borne in mind, as a fundamental maxim of sewage irrigation, that whatever system of irrigation is adopted the arrangements must be such as to absolutely prevent putrefying sewage from standing in puddles on the ground.*

acre served, American values. With the experience which has been gained there they can, however, be made at the present time at a somewhat less figure.

The necessity for economizing water in ordinary irrigation operations has led to a considerable use of pipe systems of distribution in a number of localities in the West, as for instance at Los Angeles and vicinity in Southern California, where cement concrete, vitrified tile, and light wrought-iron pipes have been extensively used for this purpose. The cost of these systems has ranged in California from $15 to $50 per acre, depending upon the area served, topographical conditions, etc. The hose and jet are not, however, used, except incidentally, in the common irrigation practice in the West, the cost of the additional labor prohibiting such use. The distribution is effected from a cheap form of cast-iron hydrant designed specially for irrigation practice. As an example of such a device which has come to the authors' notice, the California irrigation hydrant manufactured at Los Angeles may be mentioned.

* Rawlinson's Suggestions contain a number of useful hints on the preparation of irrigation areas, some of which may be quoted:

In preparing land to receive sewage the greatest economy should be used. . . . Costly brick or earthenware carriers need not be made for towns below 10,000, but main carriers can he constructed, in concrete, while tributary carriers can be formed with a spade or be ploughed into shape. Main carriers should be in level lengths, as any required fall can be obtained by vertical steps. On some sewage farms more money has been expended per acre in surface forming and levelling than the first cost of the land, in this way more than doubling the rent without giving an equivalent benefit to the land. In some other cases nothing has been done to the land but to bring the sewage and flood it on in a slovenly way—growing weeds rather than grass—both extremes are to be avoided. Crude sewage may be taken to land in cheap conduits, and may be applied direct in thin films from contour grips, so as to flow regularly and evenly on to the land, where it will be absorbed at once without being any cause of nuisance.

Tanking sewage to deposit solids, and straining sewage through material of any sort or under any arrangement of screens, only abstracts the grosser portions of the solids and flocculent matters. Sewage may, however, be deprived of much of its noxious matter in tanks, as also by passing it through what are termed filters; but the fluid remains unpurified, and is only in an improved state to be used in irrigation over heavy land; or to be passed on to a prepared deep-drained land-filter; light free soils will receive crude sewage without causing nuisance.

. . . .

The best land for a sewage farm will have a free loamy soil and open subsoil; the surface will be tolerably even, having a southern aspect gently sloping to the south.

Clay land will require deep draining and to have the surface well broken up, either by spade labor or by deep steam-ploughing; the drains must be so laid and protected as to remove subsoil-water after filtration, and not unfiltered surface water or sewage through cracks direct to the drains.

Every area, however rough or uneven, may have level contour lines set out over its entire surface, so that by forming conduits on these contour lines the surface may be irrigated. It will not therefore be necessary to spend large sums of money to lay a sewage farm out like a bowling-green.

Land having an irregularly and steeply sloping surface may have sewage-intercepting drains and carriers so arranged as to intercept the sewage from the upper areas and bring it over the lower areas a second or third time, by such means more effectively purifying the sewage.

When land has been properly prepared for the reception of sewage, it may be irrigated in all weathers, so as to purify the sewage.

The catchwork system has ordinarily cost, for original preparation of area, from $10 to $30 per acre, English prices.

In Fig. 13* is illustrated a ridge and furrow system with main carrier AA constructed of concrete masonry. Distribution carriers on the ridge are shown at D and D, with a catch-furrow at I. The main carrier is dammed by closing the gate F and the flow deflected to the distribution carriers by opening the gates G and G; from these the flow is again deflected over the slopes by the gates D and D, the por-

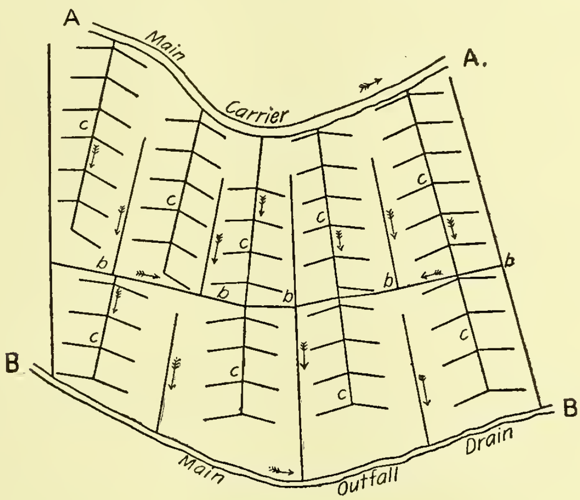


Fig. 15.—Distribution System Applicable to Land with Uniform Slope.

tion which is not absorbed finally finding its way into the catch-furrow I.

Fig. 15 illustrates a system which may also be employed on land with a gentle slope in one direction only. By it the sewage flows

A wet season does not necessarily injure a sewage farm, if the means of removing and consuming the produce are equal to the growth of the crops.

One (*Imperial*) gallon of sewage weighs 10 lbs.; 224 gallons, or 2,240 lbs., are one ton; 22,400 gallons, or 224,000 lbs., are 100 tons—equal to one inch in depth over one acre of land. Ten inches equals 1,000 tons, and 12,000 tons per acre per annum equals 120 inches in depth, and this volume may be used on well-prepared land without swamping it, as land will filter several inches in depth per day when the sewage is equally and evenly distributed.

Italian rye grass will dispose of most sewage and give heavy crops if the roots are young. The greatest producing-power will be in the first year's growth. A second year is probably the utmost length of time it should be in the ground.

No larger area of Italian rye grass should be sown than the grass upon it can be disposed of in the district, as it will not keep nor bear distant carriage. Sewage-grown grass will make good and wholesome hay if the season will permit, or if the grass can be artificially dried. (*See chapter on Use of Silo.*)

To give a sewage farm the chance of paying, the land must be obtained at a reasonable price and the costs of preparation must be moderate; there must also be reasonable skill in cropping, in cultivation, and in management, under which conditions land irrigated with sewage ought to pay a reasonable rent. If steam-power has to be used for pumping the sewage, this of course must be paid for in addition.

* From 7th Rept. Mass. St. Bd. Health.

under control through secondary carriers along the line of greatest descent; it is deflected from these by gates into the minor carriers which lead from the secondary carriers at right angles across the line of greatest descent, and overflowing the edges, spreads over the surface of the beds from above downward.

Fig. 16 illustrates a method of distribution which may be used in a field with a ridge running through it.

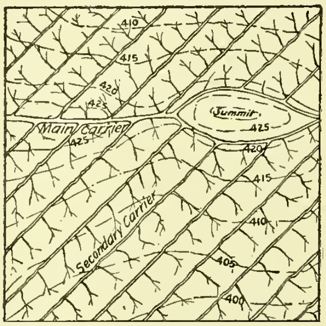


Fig. 16.—Distribution System Applicable to a Field Intersected by a Ridge.

With regard to secondary carriers, the present practice is to make them as simple as possible and, so far as may be, of a temporary character by use of spade or plow, the advantage of this treatment being that when fouled by the subsidence of suspended matter they may be purified by simply filling with clean earth and digging others to take their place.

A modification of the pipe and open carrier system, suitable for mild climates, is shown in Fig. 17.

The use or omission of these various refinements will materially influence the first cost in any given case, and clearly much must be left to the judgment of the designing engineer.*

Underdraining.

In discussing the preparation of ridge and furrow irrigation beds in the foregoing, it has been remarked that the ordinary rules of underdraining may be followed. In the case of heavy clay lands, however, an exception to this rule may be noted. Such soils possess the property of cracking in dry weather by reason of the contraction of the clay

* The practical detail of laying out irrigation areas has been discussed at various times in the Jour. of the Roy. Ag. Soc. of Eng., and the following papers contained therein may be consulted:

(1) On the Theory and Practice of Water-Meadows. By Ph. Pusey, M.P., vol. x. (1849), p. 462. In this paper the methods of forming both ridge and furrow, and catchwater systems are given.

(2) Some Account of the Formation of Hill-side Catch-Meadows at Exmoor. By Robert Smith, vol. xii. (1851), p. 139.

(3) On an Improved System of Irrigation. By John Bickford, vol. xiii. (1852), p. 162.

(4) On an Improved and Cheaper System of Laying-out Catch-Meadows. By Sir Stafford Northcote, Bart. vol. xiii. (1852), p. 172.

(5) Review of "Italian Irrigation," by R. Baird Smith, Captain of Engineers, etc. By P. H. Frere, vol. xxiv. (1863), p. 173.

Burns' Outlines of Modern Farming, Part V., contains the detail of preparation of sewage irrigation areas.

as it loses water; hence the thorough draining of clay soils is likely to result in an intensification of the tendency to crack. This will be appreciated by considering that undrained clay frequently shows cracks at least an inch in width, and of considerable depth. When

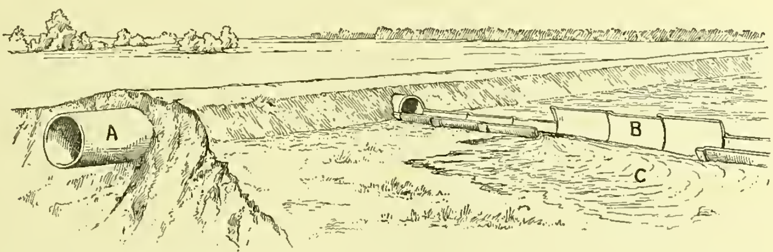


FIG. 17.—COMBINED PIPE AND OPEN CARRIER SYSTEMS OF DISTRIBUTION.

such soil is underdrained the cracking is so increased that the applied sewage will at times pass directly down to the drains without any purification at all. This practical difficulty renders the use of heavy clay soils undesirable for sewage irrigation when any other soil can be obtained.

In some cases, unfortunately, heavy clays are the only soils available, and their utilization becomes in such cases a question of considerable importance.

At the Wimbledon Sewage Farm near London, where heavy clays are successfully irrigated, the following system has been adopted for portions recently laid out, as described by Mr. Crimp: *

The surfaces were very carefully levelled to prevent any ponding; the land was divided into plots of about 4 acres by means of roads 12 feet in width; under the centre of each road a drain was laid at a depth of about 6 feet; the surface, prior to being cropped, was ploughed to a depth of about 9 inches, and while in a rough condition, a thick coating of screened town ashes was placed upon it; the ordinary agricultural operations followed, and, as a result, a porous surface of upward of a foot in thickness has been obtained, through which the sewage passes in a lateral direction. As the ground is ploughed every other year, the porosity of the surface is maintained, and the results have hitherto been satisfactory; certainly the troubles experienced in the older parts of the farm have been altogether wanting on the newer portions. The farm manager, Mr. Snook, recommends occasional subsoiling, in addition to deep ploughing, for clay soils. These disturbed surfaces will absorb large quantities of sewage, and if the liquid be carefully and intermittently applied, "lateral filtration" will occur with satisfactory results; the quantity applied per acre per day should not exceed 20,000 gallons, and with that quantity properly applied it is doubtful if any water will escape that has not been in actual contact with the soil. The volume might appear to be large, seeing that 40 gallons of sewage per head per day, 500 persons per acre would be the unit, but it is rarely the case that more than one-fifth of a sewage farm is under irrigation at any one period.

* Sewage Disposal, p. 106.

Irrigation Practice.

The process of sewage irrigation consists in allowing the sewage to flow intermittently over the surface of the land, for a few hours at a time; the interval between periods of flow being regulated by the necessities of the crops raised. Some crops, as for instance vegetables, will take considerable amounts of sewage at certain periods of growth, while later on, when maturing, the sewage needs to be kept entirely off. This principle, moreover, is not applicable to sewage irrigation alone, but applies to any kind of irrigation whatever. Thus the California fruit growers have learned as the result of experience not to irrigate orchards after the period of rapid growth has taken place; they find, by stopping the irrigation when maturity begins that the final result is a hard, crisp, juicy fruit, as finely flavored as that grown in the most favored regions, where irrigation is unnecessary.

Sewage Irrigation Fallacies.

This experience of the California fruit growers is specially referred to because there are some fallacies in regard to sewage farming floating about, which, while exploded many years ago in England, where they mostly had birth, are occasionally cropping up in this country with as much vigor as though they were new discoveries. One of these is that vegetables from sewage-irrigated farms are of necessity watery; another is that cows fed on sewage-grown grass give less rich milk than those fed on ordinary grass; and a third, which may be considered a corollary to the first two, that sewage-grown products are less healthful than those from an ordinary farm. In regard to all these points the English experience is amply sufficient to demonstrate that, with proper management of the irrigated areas, no difficulty will be found in securing products which are fairly equal to those from ordinary farming. In considering the real significance of much of the popular discussion of the value of sewage-grown produce which has taken place in England, it must be remembered that in the early days of sewage purification very extravagant views were entertained in regard to the value of the sludge to be obtained from chemical purification processes for manurial purposes. The difficulty of so utilizing the manurial elements of untreated sewage in farming operations as to return a commercial profit was realized at an early day, and large amounts of capital were embarked in chemical processes, nearly all of which were either secret or patented. The irrigation processes, on the contrary, were unprotected by patents, and in the fierce commer-

cial competition which ensued many statements in regard to their utility passed current for a time, which are not substantiated in the light of later experience.

Report of the Sewage of Towns Commission.

Questions in relation to the benefits which may be derived from properly conducted sewage irrigation were probably more thoroughly discussed in the three reports of the Sewage of Towns Commission than in any other place.* This Commission, as originally constituted, consisted of the Earl of Essex, Henry Ker Seymer, Robert Rawlinson, Professor Way, J. B. Lawes, Dr. Southward Smith, John Simon, and Henry Austin. Mr. Brunell was also appointed on the Commission, but was subsequently relieved from serving on request. The Commission begin in their first report by giving a résumé of the more salient questions of sewage purification of the day, as the result of which they state that they have arrived at the following conclusions :

1. That the increasing pollution of the rivers and streams of the country is an evil of national importance, which urgently demands the application of remedial measures ; that the discharge of sewage and of the noxious refuse of factories into them, is a source of nuisance and danger to health ; that it acts injuriously not only on the locality where it occurs, but also on the population of the districts through which the polluted rivers flow ; that it poisons the water, which in many cases forms the sole supply of the population for all purposes, including drinking ; that it destroys the fish, and generally that it impairs the value and the natural advantages derived from rivers and streams of water.

2. That this evil has largely increased with the growing cleanliness and internal improvements of towns as regards water-supply and drainage ; that its increase will continue to be in direct proportion to such improvements ; and that as these improvements are yet very partial, the nuisance of sewage, already very sensibly felt, is extremely slight as compared to what it will become when sewage and drainage works have been carried into full effect.

3. That in many towns measures for improved water-supply and drainage are retarded, from the difficulties of disposing of the increased sewage which results from them ; that the law which regulates the rights of outfall is in an anomalous and undefined condition ; that judicial decisions of a conflicting character have been arrived at in different instances, and that consequently the authorities of towns have constantly before them the fear of harassing litigation.

4. That the methods which have been adopted with the view of dealing with sewage are of two kinds : the one being the application of the whole sewage to land, and the other that of treating it by chemical processes, to separate its most offensive portions ; that the direct application of sewage to land favorably situated, if judiciously carried out and confined to a suitable area exclusively grass, is profitable to persons so employing it ; that where the conditions are unfavorable, a small payment on the part of the local authorities will restore the balance.

5. That this method of sewage application, conducted with moderate care, is not productive of nuisance or injury to health.

6. That when circumstances prevent the disposal of sewage by direct application to land, the processes of precipitation will greatly ameliorate, and practically obviate, the evils of sewage outfalls, especially where there are large rivers for the discharge of the liquid ; that such methods of treating sewage do not retain more

* 1st, 2d, and 3d Repts. Sew. Towns Com., 1858-1861-1865.

than a small portion of the fertilizing matter, and that although in some cases the sale of the manure may repay the cost of production, they are not likely to be successful as private speculations.

7. That, considered merely as the means of mitigating the nuisance, these precipitating processes are satisfactory; that the cost of them in any case is such as town populations may reasonably be called upon to meet; that the necessary works need not, if properly conducted, be a source of nuisance; and that, by modifications of the existing methods, even the slightest risk of nuisance may be entirely obviated.

8. That the employment of the one or other method of disposing of sewage, or of both conjoined, must depend upon locality, levels, markets, and a variety of other circumstances, and that the case of each town must be considered upon its own peculiarities.

9. That there is good ground for believing that the methods yet proposed for dealing with sewage are not the best that can be devised, and that further investigation will probably result in the discovery of processes more thoroughly equal to the suppression of the nuisance, and at the same time calculated to give more valuable products.

10. That the magnitude of a town presents no real difficulty to the effectual treatment of its sewage, provided it be considered as a collection of smaller towns.

In their second Report the Sewage of Towns Commission state that a committee of members of the Commission personally visited and examined a number of rivers and streams which are reported as seriously polluted. They also state the result of examining various chemical processes of purification, together with statement in detail of the results, to the date of the second Report, of the series of experiments carried out by J. B. Lawes at Rugby, by order of the Commission.

The object of these experiments is stated as being to determine so far as possible:

1. The amount and composition of the produce in relation to the volume of water supplied to the land by irrigation, to the amount of manurial constituents so applied, and to the population contributing the manurial constituents of the water.

2. The most profitable method of applying the produce, that is, whether it should be used in the green state or as hay; whether for the production of milk or as meat; and whether it should be consumed alone or in conjunction with other food.

For the purpose of the experiments, two fields of five acres and ten acres area, respectively, were selected, and each divided into four equal parts. The four plots of each field were treated as follows:

Plot 1, without sewage; Plot 2, with 3,000; Plot 3, with 6,000; and Plot 4, with 9,000 (long) tons of sewage per acre per annum.

In Tables Nos. 54 and 55 are given some of the results of the experiments on the two fields. Table No. 54 shows the amount of grass raised on each of the four plots for the years 1861–1863. Table No. 55 is self-explanatory. Table 56 gives the results of a series of experiments in feeding sewage grass to milch cows. The figures in Table 54 have been reduced, from long tons, hundredweight, quarters, and pounds, to an equivalent in pounds, for convenience.

TABLE No. 54. — RESULTS OF THREE YEARS' EXPERIMENTS AT THE SEWAGE-FARM IN RUGBY, ENGLAND.

Year.	Five-acre field.				Ten-acre field.			
	Without sewage.	With sewage.			Without sewage.	With sewage.		
	Lot 1	Lot 2	Lot 3	Lot 4	Lot 1	Lot 2	Lot 3	Lot 4
1861	20,814	33,244	60,602	73,564	19,951	35,478	51,028	59,792
1862	18,294	62,514	77,299	71,766	36,985	61,732	71,946	70,832
1863	11,069	49,851	78,231	80,941	18,023	56,596	68,500	78,337
Average	16,725	48,536	72,044	76,424	24,986	51,268	65,825	69,654

TABLE No. 55.— PER CENT. OF DRY SUBSTANCE IN CROPS RAISED ON EXPERIMENTAL FIELDS.

Number of crop.	Five-acre field.				Ten-acre field.			
	Without sewage.	With sewage.			Without sewage.	With sewage.		
	1	2	3	4	1	2	3	4
1861.								
1	27.9	30.5	26.9	27.7	22.0	23.3	21.4	18.4
2	24.4	19.8	14.2	13.3	26.9	17.1	15.1	16.1
3	....	13.4	13.7	12.9	....	12.6	7.3	14.4
4	....	....	15.4	9.6	....	16.9	15.1	17.8
Mean	26.2	21.2	17.6	15.9	24.5	17.5	14.7	16.7
1862.								
1	26.7	22.8	14.4	15.3	26.9	19.5	13.5	13.1
2	22.8	14.3	16.4	19.4	17.9	16.2	19.0	16.7
3	....	18.2	12.9	14.2	....	14.5	14.4	15.8
4	....	....	....	....	....	....	33.8	33.8
Mean	24.8	18.4	14.6	16.3	22.4	16.4	15.6	15.2
1863.								
1	36.1	21.5	17.6	16.3	39.8	18.6	20.0	14.6
2	34.4	18.5	14.9	17.8	18.2	17.7	16.3	18.8
3	....	17.7	10.9	17.6	....	12.4	14.6	15.2
4	....	15.8	13.0	12.3	....	....	13.9	13.6
5	....	....	....	15.3	....	....	....	....
Mean	35.3	18.4	14.1	15.9	29.0	16.2	16.2	15.6

In the third report the discussion of these experiments is continued, and the Commission gives in detail the results obtained from definite areas treated, under the following heads :

1. Quantities of sewage applied and of green produce obtained.
2. Experiments with Italian rye-grass.
3. Experiments with fattening oxen.
4. Experiments with milking cows.
5. Composition of the Rugby sewage water.
6. Estimated composition of Metropolitan sewage.
7. Composition of the Rugby drainage water. (Effluent.)

TABLE No. 56.—RESULTS OF FEEDING UNSEWAGED AND SEWAGED GRASS TO MILCH COWS.

(Parts per 100.)

	Cows fed on grass alone.		Cows fed on grass and oil-cake.	
	Unsewaged, mean of nine samples.	Sewaged, mean of ten samples.	Unsewaged, mean of four samples.	Sewaged, mean of four samples.
Caseine	3.246	3.241	3.352	3.423
Butter	3.604	3.430	3.657	3.707
Sugar of milk, etc.	4.405	4.218	4.561	4.689
Mineral matters	0.753	0.776	0.740	0.771
Total solids	12.008	11.665	12.310	12.050
Water	87.992	88.335	87.690	87.950
Total	100.	100.	100.	100.

8. Composition of the unsewaged and sewaged grass.
9. Effects of sewage on the mixed herbage of grass-land in developing the more freely growing at the expense of the less freely growing plants.
10. Composition of the milk yielded from the unsewaged and sewaged grass.
11. Experiments of the application of sewage to oats in 1863.
12. Miscellaneous results obtained in 1864.

All the questions formally enumerated in the foregoing are discussed in the Report in detail, finally followed by a summary in which the main points in the discussion are saliently presented. The report as a whole furnishes the most complete information on the subject treated that has thus far been given. The more useful portions of the summary are as follows:

1. As there is a daily supply of sewage the year round, which, on sanitary and engineering grounds, it is essential to dispose of as soon as it is produced, and as passing it over land is the best mode both of purifying and utilizing it, it should be employed for purposes of irrigation, and be applied in winter, when of comparatively little value, as well as in summer, when of more.

RESULTS OBTAINED ON THE APPLICATION OF SEWAGE TO MEADOW AND ITALIAN RYE-GRASS.

2. By the application of sewage to grass land during the winter months a very early cut or bite of green food may be obtained, but the amount of increased produce due to the winter application is comparatively small for the amount of sewage employed.
3. By means of sewage irrigation the period during which an abundance of green food was available was extended considerably at the end as well as at the beginning of the season, and the more so the larger the quantity of sewage applied, almost up to the highest amount employed—namely, 9,000 tons per acre.*
4. One of the experimental fields gave much less produce per acre without sewage than the other, and analysis showed its soil to be much less naturally fertile; but it gave fully as much produce per acre under the influence of liberal dressings of sewage as the naturally much more fertile soil.

* It will be understood that in this quotation long tons (2,240 pounds) are meant.

5. Taking the average over three years, and in the two fields, the amount of produce obtained without sewage was about 9¼ tons of green grass per acre per annum, equal about 3 tons of hay; and with 3,000, 6,000, and 9,000 tons of sewage per annum the amounts were, respectively, about 22¼, 30¼, and 32½ tons of green grass—equal respectively (reckoned according to the percentage of dry substance in each) about 5, 5¾, and 6½ tons of hay.

6. The largest quantities of produce per acre were obtained in the third year of the experiments, and with 9,000 tons of sewage per acre per annum; namely, in one field 35 tons, and in the other 37 tons of green grass, equal respectively about 6 tons 12¾ cwts., and 7 tons 1 cwt. of hay.

7. The average increase obtained for each 1,000 tons of sewage was—when 3,000 tons per acre per annum were applied, about 5 tons of green grass; when 6,000 tons were applied, 4 tons 2½ cwts.; and when 9,000 tons were applied, 3 tons 3¼ cwts. of green grass.

8. The amount of produce per acre was the greater, the greater the quantity of sewage applied, up to 9,000 tons per acre; but the amount on increase of produce obtained for a given amount of sewage was the less where the greater amounts were applied.

9. Experiments with rye-grass were made in one season only, sewage was not applied until the end of April, and comparatively small quantities were put on. The results so obtained indicated much about the same amount of increase of produce for a given amount of sewage as with meadow grass.

RESULTS OBTAINED WITH FATTENING OXEN.

10. When cut and given to fattening oxen tied up under cover, more sewaged than unsewaged grass, reckoned in the fresh or green state, was both consumed by a given weight of animal within a given time, and required to produce a given weight of increase; but, of real dry or solid substance, less of that of the sewaged than of the unsewaged grass was required to produce a given effect.

11. When cut grass was given alone the result was very unsatisfactory; but when oilcake was given in addition the amount of increase upon a given weight of animal within a given time, and for a given amount of dry substance of food consumed, was not far short of the average result obtained when oxen are fed under cover on a good mixed diet.

12. The money return, whether reckoned per acre or for a given amount of sewage, was much less with fattening oxen than with milking cows.

RESULTS OBTAINED WITH MILKING COWS.

13. When cows were fed on unsewaged, or sewaged grass, as much as they chose to eat, a given weight of the animal was more productive, both of milk and increase, but especially of milk, on the unsewaged than on the sewaged grass.

14. From a given weight of unsewaged grass, reckoned in the fresh or green state, more milk was produced than from an equal weight of fresh sewaged grass; but a given weight of the dry or solid substance supplied in sewaged grass was on the average more productive than an equal weight supplied in unsewaged grass.

15. The milk-producing quality of the grass was very different in different seasons, and at different periods of the same season. It was very inferior in the wet and cold seasons of 1862, and toward the close of the seasons as compared with the earlier periods. It appears probable that Italian rye-grass deteriorates less toward the end of a season than meadow grass. On the average, about six parts by weight of fresh grass yielded one part by weight of milk.

16. By the aid of sewage, the time that an acre would keep a cow, and the amount of milk yielded from the produce of an acre, were increased between three- and four-fold.

17. So far as the results of the experiments afford the means of judging, it is estimated that with an application of about 5,000 tons of sewage per acre per

annum to meadow land, an average gross produce of not less than 1,000 gallons of milk per acre per annum may be expected.

18. In experiments conducted with Italian rye-grass (but in one season only), more milk was obtained by the use of a given amount of sewage applied to it than meadow grass.

19. With an application of about 5,000 tons of sewage per acre per annum, an average gross return of from 306 to 356 per acre, in milk at 8d. per gallon, may be anticipated.

COMPOSITION OF THE RUGBY SEWAGE.

20. The mean of 93 analyses, of as many samples, of the Rugby sewage, collected over a period of 31 months, shows 6½ grains of ammonia, and 87½ grains of total solid matter, per gallon; equal to 207¾ lbs. of total solid matter per 1,000 tons. Or, taking the mean of the average composition fixed by the analyses for each of the 31 months, instead of the direct mean of the total 93 analyses, the average contents would be almost exactly 7 grains of ammonia, and 92½ grains of total solid matter per gallon; equal to 224 lbs. or 2 cwts. of ammonia, and 2,960 lbs., or about 26½ cwts. of total solid matter, per 1,000 tons.

21. Although each sample analyzed was the mixture of portions taken every two or three hours for several days together, the variation in composition at different times was very great; the amount of ammonia varying in the different mixed samples from 2½ to about 15½ grains per gallon, or from 81½ to 500½ lbs. per 1,000 tons, whilst the total solid matter varied from about 37½ to about 270 grains per gallon, or from 1,203 to 8,637 lbs. per 1,000 tons.

22. 1,000 tons of the average sewage of Rugby represent the excretal and other matters of from 17 to 18 average individuals of a mixed population of both sexes and all ages for a year, and contain ammonia equal to that in from 11 to 12 cwts. of Peruvian guano; or about 1,700 tons of such sewage would contain nitrogen reckoned as ammonia equal to that in 1 ton of Peruvian guano.

23. It is estimated that there are at Rugby, including rainfall, etc., on the average from 55 to 60 tons of sewage per head of the population per annum.

24. Judging from the average composition of the Rugby sewage and of various crops, it is concluded that potash would be more likely than phosphoric acid to become deficient where town sewage was applied constantly to grass land, while phosphoric acid would be more likely to become deficient than potash if it were applied to the ordinary crops of rotation.

. . . .

CHEMICAL COMPOSITION OF THE GRASS.

35. The sewaged meadow grass, as cut and given to the animals, contained a less proportion of dry or solid substance than the unsewaged; and the grass cut during the later portions of the season (both unsewaged and sewaged) contained less solid matter than that cut during the more genial periods of growth.

36. Italian rye grass, in the condition as cut, was also found to be more succulent and to contain less solid matter when grown with sewage than without it; but the proportion of dry substance diminished less as the season advanced in its case than in that of the meadow grass.

37. The proportion of nitrogenous substance (and also of impure waxy or fatty matter) was much greater in the solid matter of the sewaged than in that of the unsewaged grass. The proportion of nitrogenous substance was also much higher in the solid matter of the grass grown toward the end than earlier in the season. The proportion of indigestible woody fibre was much about the same in the dry substance of the unsewaged and of the sewaged grass. It progressively diminished as the season advanced, and was generally lower in the dry substance of the Italian rye than in that of the meadow grass.

38. A given amount of the dry substance of grass grown in a cold and wet season, or during the cold and wet periods of the year, generally contains more nitroge-

nous substance, but is less productive than that of grass grown in more genial weather.

39. The greater productiveness in milk and increase of a given amount of the solid matter of the sewaged grass appears to depend more on a favorable condition of maturation, digestibility, and assimilability of the constituents than on the actual percentage amount of any of those determined and above enumerated.

EFFECTS OF SEWAGE ON THE MIXED HERBAGE OF GRASS LAND.

40. The effect of sewage irrigation on the mixed herbage of grass land is to develop the graminaceous plants chiefly, nearly to exclude the leguminous, and to reduce the prevalence of miscellaneous or weedy plants, but much to encourage individual species.

41. Among the grasses which have been observed to be the most encouraged by sewage are (according to locality or other circumstances) rough meadow grass, couch grass, rough cock's foot, woolly soft grass, and perennial rye grass ; two or three only remaining in any considerable proportion after sewage has been liberally applied for some years.

42. The produce of sewage-irrigated meadows being generally cut or grazed very young, the tendency which the great luxuriance of a few very free-growing grasses has to give a coarse and stemmy later growth is not an objection, as in the case of meadows left for hay ; a given weight of the dry or solid substance of the more simple sewaged grass being, when consumed green, more productive than an equal weight of that of the more complex unsewaged herbage.

COMPOSITION OF THE MILK FROM THE UNSEWAGED AND THE SEWAGED GRASS.

43. Although more milk was obtained from a given weight of the dry or solid substance of sewaged than of unsewaged grass, there was comparatively little difference in the composition or richness of the milk from the two kinds of grass. That from the sewaged grass was, however, slightly the less rich, containing somewhat less of casein, butter, sugar, and total solid matter (though more mineral matter) than that from the unsewaged.

44. When oil-cake was given with the grass (whether sewaged or unsewaged), the richness of the milk was notably increased.

RESULTS OBTAINED ON THE APPLICATION OF SEWAGE TO OATS.

45. In an experiment with oats, in which 135½ tons of sewage were applied per acre, the gross value of the increased produce amounted to more than 5*d.* per ton of the sewage employed, or to about three times the market value of the constituents of the sewage, supposing them to have been extracted and dried ; and in another experiment, in which 510 tons were applied per acre, the gross value of the increased produce amounted to about 1¼*d.* per ton of the sewage employed.

46. In the experiment with the smaller quantity of sewage the supply of water was equivalent to something under an additional 1½ inch of rain at the critical period of growth, and in that with the larger amount to about 5 inches, which proved to be a great excess at the period of the season at which it was applied, there being an over-production of straw, and the crop being much laid. Both experiments were made in the unusually productive season of 1863, and with sewage of about double the average strength of that of the Metropolis, which was applied during a period of very dry weather. It is obvious, therefore, that the results were quite exceptional, and cannot be taken as indicating what might be expected from the application of small quantities of sewage to corn crops on different soils and on the average of seasons.

47. It is probable that 500 tons of sewage per acre is more than would be appropriate to arable land otherwise treated in the ordinary way, taking the average of soils and seasons ; and it is certainly more than would be appropriate for heavy lands and for wet seasons.

GENERAL CONCLUSIONS.

48. To obtain a maximum amount and gross value of produce from a given amount of sewage, it should be applied in small quantities per acre and in dry weather; but the great dilution of town sewage, its large daily supply at all seasons, and its greater amount in wet weather, when the land can least bear, or least requires, more water, render it quite inappropriate for application on a comprehensive scale to arable land for corn and other ordinary rotation crops.

49. Supposing arrangements were made for distributing sewage over a sufficiently large area to command a full value, both as manure and as water, at the most favorable periods of the year, the cost of main distribution would be very great; the application to the arable land would require to be chiefly by the expensive means of piping and hose and jet, instead of open runs, and but a small proportion of the total sewage could be so used, leaving the remainder to be applied in large quantities to grass land, at the less favorable periods of the year, and of course to realize a much lower value.

50. Having regard to the cost of distribution, it is probable that the most profitable mode of utilization would be to limit the area by specially adapting the arrangements for the application of the greater part, if not the whole, to permanent or other grasses laid down to take it the year round, trusting to the occasional use to other crops within easy reach of the line or area so commanded, but relying mainly on the periodically broken up rye-grass land and on the application to arable land of the solid manure resulting from the consumption of the sewaged grass for obtaining other produce than milk and meat by means of sewage.

51. It is probable that about 5,000 tons of sewage per acre, judiciously applied to grass land properly laid down to receive it, would, in a great majority of cases, secure the most profitable utilization.

52. Supposing an application of 5,000 tons of sewage per acre per annum to grass land, the purification of the water would doubtless be sufficient to admit of the drainage being turned into the rivers without fear of detriment to fish; while any streams receiving such drainage, instead of that direct from the towns, would at any rate be vastly improved from their previous condition as a water-supply: but whether the purification would be sufficient with such an application is a question which requires further experience and investigation to answer satisfactorily, and which will probably receive a different answer in different cases.

53. Assuming that the average dilution of the Metropolitan sewage, including rainfall and subsoil water, will amount to 100 tons per annum, 5,000 tons would represent the excretal and other matters of 50 average individuals; and a population of 3,000,000 would require about 60,000 acres constantly under irrigation.

54. The only records of exact quantitative results obtained on the application of town sewage to corn crops are those of the experiments of the Earl of Essex on wheat, and those of the experiments with oats at Rugby, given in this Report, and in both cases the increase of produce represented a very high gross money return per ton of sewage employed. The circumstances of the experiments at Rugby were, however, quite exceptional; and, where the most extensive trials of the application of sewage to corn crops have been made with a view to profit—namely, at Watford, Rugby, and Alnwick—the practice has been abandoned; while neither at Edinburgh, nor Croydon, where the best results have been obtained with grass, does the application to corn and other rotation crops constitute a part of the general system adopted.

55. Judging both from the results of the experiments, and from the experience of common practice, it is considered that the most profitable utilization of town sewage will in most cases be attained by the application of about 5,000 tons per acre to meadow or Italian rye grass, but that the farmer would not pay $\frac{3}{4}$*d.*, and probably not $\frac{1}{2}$*d.*, per ton, the year round, for sewage of the average strength of that of the Metropolis (excluding storm water), delivered on his land.

The experiments of the Sewage of Towns Commission indicate varying amounts of sewage as applicable to different crops, the quan-

tity necessary for efficient results ranging from less than 500 gross tons per acre per annum on heavy land, in wet seasons, to about 9,000 tons per acre on grass lands. Assuming, for American conditions, a daily average of 80 U. S. gallons per head, the sewage of each person amounts to 97 gross tons per annum; whence we derive that the application per acre per annum will, according to the Sewage of Towns Commission, vary from the sewage of 5 persons to 93. If we include some additional sewage which the land may be made to clarify without reference to the results of cropping, we may take from 50 to 150 persons per acre as the average for the whole year, though the quality of the soil and the amount of dilution of the sewage will both influence the result. With unfavorable soils and a large dilution, 50 persons per acre will be sufficient; while, with favorable soils and a concentrated sewage, we may go as high as from 150 to 200 persons to the acre. The proper solution in each case will depend entirely upon the local conditions. *

The Royal Agricultural Society's Sewage Farm Competition.

In 1879 the Royal Agricultural Society of England offered two prizes each of the value of £100 for the best-managed sewage farms in England and Wales.† Messrs. Baldwin Latham, Clare Sewell Read, and Thos. H. Thursfield were designated as the judges to make the award.

In the first class the following sewage farms were entered: Aldershot, Bedford, Guisborough, and Wrexham; in the second class, Birmingham, Croydon, Doncaster, Reading, and Leamington. The report of the judges contains full information in regard to the area, cost of operation, population contributing sewage, and various other items necessary to a full understanding of the relative efficiency of the several different farms. A tabulation is also given of the chief physical properties of the soils of the different farms, the whole followed by a statement in detail in regard to kind of crops, acreage, and various other items for each competing farm. Many of these tabulations are of great interest and value, but their length precludes introducing them here.

In class 1 the judges decided that the sewage farm of the Corporation of Bedford and that of Wrexham were equal in merit. The first prize was therefore adjudicated to them jointly.

* In the 19th An. Rept. Mass. St. Bd. Health (1888) it is stated, p. 38, that, on an ordinary farm in Mass., 2,500 gals. per acre per day are as much as could be applied to any valuable grass crop, and there would be required 400 acres of irrigation ground for each 1,000,000 gallons of sewage; from which it is concluded that irrigation alone cannot be depended upon in the more thickly settled portions of that State for preventing the pollution of streams.

† See Rept., in vol. xvi., Sec. Ser. (1880), pp. 1-80.

In class 2 the prize was awarded to the Leamington sewage farm. The judges, however, say they are strongly of the opinion that a second prize should be awarded in this class to the Doncaster sewage farm, which they deem an admirable example of thrifty management, also showing how sewage can be applied in general farming. A study of this report will be of use to any one interested in sewage farming. In regard to the crops raised, the report shows that almost any crop which can be raised in ordinary farming in England can be cultivated on properly managed sewage farms with good effect. At the Leamington farm, cropping for 1879, and the area into each crop were as follows:

	A.	R.	P.		A.	R.	P.
Italian rye grass,	49	0	37	Cabbage,	6	0	0
Seeds,	16	2	23	Barley,	18	2	0
Pasture,	86	2	14	Parsnips,	6	3	17
Potatoes,	4	0	0	Beans,	45	2	9
Oats,	18	0	5	Turnips,	23	3	24
Mangolds,	23	3	34	Wheat,	68	2	35
Carrots,	2	3	0	Rhubarb,	0	2	0
					371	0	38

The following details in regard to the crops raised at Leamington in 1879 are also given:

Rye grass.—This crop is grown both for sale and home consumption. It is not allowed to stand longer than two years, and about 25 acres are sown every year—usually in the autumn, at the rate of three bushels of seed per acre. A crop sown in September, 1877, was cut eight times in 1878 and twice in 1879, and then ploughed up; the land was pressed, sewaged, and sown on the flat broadcast on the 15th of June, 1879, with green-top turnips and swedes, which looked well and promising at the time of our visit in August. In 1878 the cutting of rye grass commenced on the 2d of February. In 1879 it commenced on the 7th of April, having been sown in September, 1878. The first cutting yielded 4 tons per acre of green grass; the second, on the 4th of June, yielded 16 tons of grass per acre; the third cutting, on the 8th of July, 14 tons of grass per acre; fourth cutting, on the 14th of August, 8 tons; fifth cutting, on the 12th of September, 6 tons; sixth cutting, on the 6th of October, 5 tons; seventh cutting, in November, 2 tons per acre. A field of rye grass was seeded as an experiment with 10 lbs. per acre of trifolium; but it did not answer. Rye grass is occasionally made into hay; but when this is the case, it is carted on to the meadows to finish the drying process. This crop receives enormous dressings of sewage during the period of its growth, as will be seen on reference to the tables showing the quantities of sewage that have been applied to the land.

Mangolds.—This is a crop largely grown on this farm. It is drilled on the flat, the drills being 26 inches distant, and the plants are hoed out to 10 inches distance in the rows. Sewage is not applied to the crop until the plants begin to bulb. They are then irrigated. This crop in 1878 received 21 dressings of sewage while under cultivation, or 8,265 tons of sewage per acre, equivalent to an irrigating depth of 81.8 inches of water in addition to the rainfall. The mangolds of 1878, when examined in the spring of 1879, we found to be sound and good, but not equal in weight and bulk to those grown on the Reading sewage farm. One field of mangolds was poor and stunted; but on the higher and light land they were a capital crop, and in all cases were clean, and the plants regular but late.

Cabbage.—Ordinary cabbages for market are planted on the level in rows 22 inches distant, and the plants are 17 inches apart in the rows. Savoys are planted in a similar manner. Drumhead cabbages are also planted on the flat, 26 inches

distant, in rows, and 24 inches from plant to plant. All the cabbages are irrigated during the period of growth, and in 1878 this crop on one field received 17 dressings of sewage, or about 6,102 tons per acre, equal to an irrigating depth of 60.4 inches.

PARSNIPS.—This crop is grown on the level. Six lbs. of seed per acre is drilled in rows 14 inches distant, and hoed out to six inches in the rows. The crop is not irrigated, but usually succeeds cabbage or the second year's rye-grass, which has been sewaged. The crop was clean, and promised to be a fair one.

CARROTS.—These are drilled in rows on the level, at 14 inches distance, and are hoed out to from 4 inches to 6 inches in the rows. Six lbs. of seed per acre are sown. This crop was not good, nor was it looking well, although it was clean. It is not directly irrigated with sewage, but, like parsnips, succeeds, either directly or after two years, a crop that has been heavily dressed with sewage.

POTATOES.—The varieties grown were "Myatt's Early Rose" and "Victoria." They are planted in drills from 24 inches to 26 inches apart, and 12 inches from plant to plant in the rows. The crop of 1879 was planted on the 9th of April, and succeeded rye-grass that had been cut four times the previous year. It was then sewaged, broken up, and sown at the end of July with turnips, which were fed off on the ground with sheep. This year the potato crop had been sold at the time of our visit in August at £17 10*s.* per acre, the buyer having to raise the crop and take all risk. Potatoes are not directly sewaged during the period of their growth, and the crop of 1879 was not so good as usual.

RHUBARB.—At Leamington, as on most sewage farms, this is one of the permanent crops. It costs about £50 per acre to purchase roots, prepare the ground, and plant out; and the crop realizes about £40 per acre every year. The roots, however, require to be taken up every three years, to be divided and replanted; they are planted 30 inches apart, and are irrigated with sewage during the period of growth. After the pulling for market is finished, no further use is made of the crop. The purchaser of the crop pulls and markets the produce.

WHEAT.—A large acreage of this crop is grown on the farm, but as a rule not under the influence of sewage. Taking the fields of wheat grown during 1879, we found in the first example that the previous crops had been bare fallow in 1878, wheat in 1877, beans in 1876, oats in 1875, wheat in 1874, beans in 1873, wheat in 1872, permanent pasture and mangolds in 1871, and none of these crops were irrigated. The second example was immediately preceded by barley in 1878, turnips in 1877, wheat in 1876, beans in 1875, wheat in 1874, mangolds in 1873, wheat in 1872, and swedes and peas in 1871. The turnip crop preceding barley was irrigated in 1877. The wheat stubble was irrigated in 1874 and the bastard fallow for wheat in 1872. The third example was immediately preceded by beans in 1878, and before that by grass in 1877, mangold, cabbage, etc., in 1876, parsnips and potatoes and carrots in 1875, parsnips and potatoes in 1874, wheat in 1873, Italian rye-grass in 1872, and Italian rye-grass in 1871. Mangolds were sewaged in 1876, cabbages, etc., in 1875, bastard fallow was sewaged in 1874, and rye-grass in 1872. The wheat crop of the present year was sown at the rate of two bushels of seed per acre, about the middle of October, 1878. The wheat was seeded with one peck of rye-grass, 10 lbs. of red clover, 5 lbs. of trefoil and alsike mixed. The plant looked well, especially the "thick set" or square-headed wheat, which promised a good if not a heavy yield. The Browick wheat was also good.

OATS.—Oats were heavy and lodged. The land was sown on the 22d of April at the rate of 4 bushels of seed per acre. This crop, like the wheat, is not directly irrigated. This year's crop succeeded Italian rye-grass, which had been grown on the farm the two preceding years, and had been heavily dressed with sewage.

BEANS.—The winter beans were drilled on the 23d of October, 1878, and were a poor plant. The spring beans, however, drilled on the 10th of March, 1879, were a capital crop. This crop is not directly irrigated with sewage. The seed is drilled in rows at intervals of 15 inches, and 3 bushels per acre are used. The preceding crops vary very much; for example, beans in 1879 were preceded in one case by wheat both in 1878 and 1877, clover in 1876, oats in 1875, mangold in 1874 and 1873, beans in 1872, and oats in 1871. The only sewage applied to these crops was

to the mangold in 1874. Another field of beans in 1879 was preceded by wheat in 1878, seeds in 1877, oats in 1876, mangolds and swedes in 1875, oats in 1874, wheat in 1873, beans in 1872, and wheat in 1871. The only sewage applied was to the mangolds in 1875. A third field of beans in 1879 was preceded by Italian rye-grass in 1878 and 1877, wheat in 1876, beans in 1875, grass in 1874 and 1873, wheat in 1872, and swedes in 1871. The crop was irrigated with sewage in 1878, 1877, 1876, 1874, 1873, and in 1872.

Barley.—Barley was a fair standing crop. It was sown at the rate of two bushels per acre on the 22d of April. The crop is not irrigated directly with sewage. Of two fields of this crop in 1879, one was preceded by turnips and parsnips in 1878; parsnips, cabbage, and turnips in 1877; potatoes, carrots, etc., in 1876; mangolds in 1875; Italian rye-grass in 1874 and 1873; barley in 1872; and swedes in 1871. Of the above crops the cabbage in 1877, fallow in 1876, fallow for mangolds in 1875, Italian rye-grass in 1874 and 1873, and fallow for grass in 1872, were irrigated with sewage. A second field of barley in 1879 was preceded by turnips in 1878, barley in 1877, wheat in 1876, clover in 1875, barley in 1874, swedes in 1873, and wheat in 1872. The clover and seeds in 1875 were the only crops previously occupying the ground that were irrigated.

Turnips and swedes.—Green-top turnips are usually sown broadcast at the rate of 3 lbs. of seed per acre, and are fed off on the ground by sheep. Swedes are also grown on this farm. They are drilled on the flat at 16 inches distant, and the bulbs are hoed out to 9 inches apart in the rows. Two lbs. of seed were drilled per acre. The crop is irrigated with sewage to a moderate extent. Turnips and swedes usually follow a straw crop of either wheat, barley, or oats, and occasionally green-top turnips are cultivated, chiefly after Italian rye-grass.

Fig. 18.—Italian Rye-grass.

Seeds are usually sown with the straw crops. The variety and quantity of seed sown has already been given under the head of wheat. Clover is occasionally irrigated in dry seasons with moderate dressings of sewage. By reference to the returns, however, we find that seeds have not been sewaged since the year 1875.

Prickly comfrey. — This is a crop which has been grown upon this farm for two years, and has been given up, as it was found that the horses and cattle would not eat the produce by choice. It appears, however, that the crop, when once planted, is difficult to eradicate from the ground, as upon the plot upon which it had been grown during the present year a number of young plants had made their appearance.

In referring to these crops it will be noticed that all of them are crops common to American farming, except Italian rye-grass, *Lolium Italicum*, shown by Fig. 18, which, while not yet cultivated to any very great extent in this country, is still one of the best known grasses in Europe. It is suited above all other grasses for irrigation, and in Italy, Scotland, and elsewhere yields on sewage-irrigated meadows prodigious crops of

forage of the best quality. It is extensively grown in Italy, and the peculiar excellence of the cheese of that country is said to be due to the quality of this grass, which is the chief food of the cattle. It is stated as not only adding to the flavor of butter and cheese, but as also increasing the flow of milk. With sewage irrigation it has yielded at times over 60 tons of green forage per acre.*

There are a number of other grasses which may be utilized in sewage irrigation, although the rye-grass properly heads the list. Osiers are also one of the most useful crops in sewage irrigation by reason of the large quantities of liquid which they can appropriate without detriment during the growing season.

TABLE NO. 57.—STATISTICS OF FOREIGN SEWAGE IRRIGATION AND FILTRATION.†

Locality.	Nature of the soil.	Remarks.	Volume of sewage. Per acre per annum, tons.	Volume of sewage. Per acre per day (yearly average), cubic feet.	Average depth of sewage per annum, feet.	Date.
Berlin, Malchow	Heavy.	Irrigation.	2,925	288	2.41	1884–85
" "	"	"	3,514	346	2.90	1886–87
Doncaster	Sand or gravel.	"	4,016	395	3.31	1878
Berlin, Falkenburg	Heavy.	"	4,907	483	4.04	1886–87
Leamington	Mostly gravel.	"	5,553	546	4.58	1878
Berlin, Osdorf	Sandy.	"	6,261	616	5.16	1886–87
Berlin, Grossbeeren	"	"	6,511	640	5.37	1886–87
Paris, Gennevilliers	Sand and gravel.	Market gardening.	13,270 ‡	1,305	10.94	1875–83
" "	"	Filtration and cultivation.	19,483	1,916	16.06	1883
" "	"	Experiments.	19,905	1,958	16.40	....
" "	"	Filtration without cultivation.	36,763	3,616	30.30	1881–82
Croydon, Beddington	Gravel.	Broad irrigation.	39,243	3,860	32.34	1878–79
Paris	Sand and gravel.	Maximum limit.	39,809	3,915	32.81	1884

† Compiled by Chas. S. Swan, M. Am. Soc. C.E. See paper, Notes on European Practice in Sewage Disposal, in Jour. Assn. of Eng. Socs., vol. vii., No. 7, pp. 248–257 (July, 1888).

‡ Working average for the series of years 1875–1883.

Table No. 57 may be taken as showing, subject to the limitations indicated, the amount of sewage which can be applied in broad irrigation to various soils.

A NEW PHASE OF SEWAGE FARMING.

The Rugby experiments of the Sewage of Towns Commission indicated that sewage-grown grass when made into hay was especially valuable food for milch cows, hence the practical deduction is to, so far as possible, operate sewage farms as dairy farms. Until recently, however, there has been a practical difficulty in the way of realizing the conclusion to which the commission arrived over 25 years ago, namely, the apparent impossibility of curing into hay the heavy crops of grass

* For more complete account of Italian rye-grass and its adaptability to American conditions, see Bull. No. 73, N. Carolina Ag. Expt. Sta. (Oct. 15, 1890), p. 30.

raised during the growing season in order to provide fodder for winter use. The sewage-irrigated grass crops have been mostly disposed of green, which has again considerably complicated the management of sewage farms. Italian rye-grass, the most valuable grass for sewage

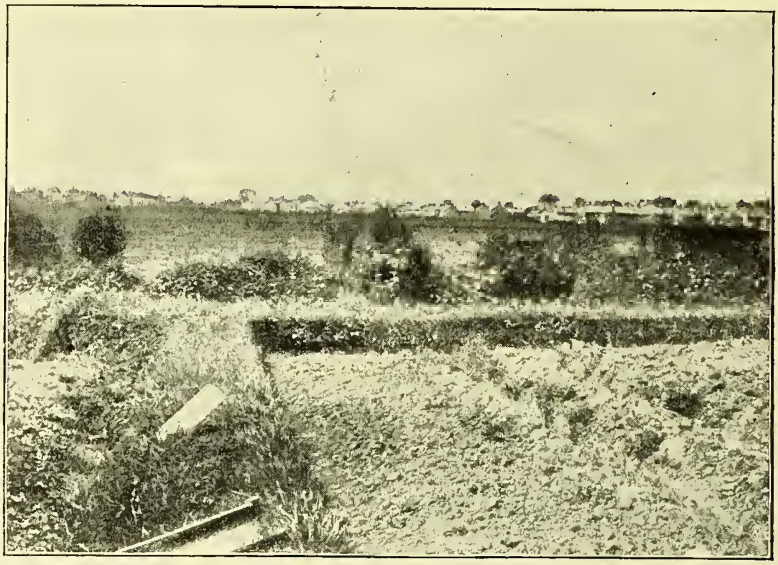


FIG. 19.—VIEW OF SEWAGE FARM AT BEDFORD, ENGLAND; FIELD BEYOND BUSHES IS USED FOR IRRIGATION.

irrigation by reason of its capacity to receive large doses of irrigation without injury, is, further, the grass which has been found the most difficult to cure into hay, especially in seasons which are at all wet. The extensive use in the last few years of silos has developed an entirely new phase to this question and may possibly, by putting it in the power of sewage farmers to make a specialty of dairying for the whole year, assist in securing an adequate commercial return on the whole investment in sewage farming operations. At any rate the subject appears of importance enough to justify a chapter On Silos and Their Use in Sewage Farming, and to that chapter the reader is accordingly referred for further information on this branch of the subject.

EXPLODED OBJECTIONS.

The objection has been frequently urged against sewage farming that the fields are likely to become exceedingly offensive from the production of an effluvium nuisance. It is true when improperly or carelessly managed they are likely to be at times open to this objec-

tion. The same is also true of neglected barnyards, although in the present state of agricultural development no one would seriously propose to abolish all barnyards because of this patent truth; nevertheless it is exactly what is proposed in the case of sewage farms. That such farms are not necessarily offensive as managed in the present time in England is abundantly shown by Figs. 19 to 21, illustrating a number of sewage-irrigated fields and showing clearly their proximity to a good grade of residential property. It is stated by Mr. Clarke, from whose report these views are taken, "that in none of these cases

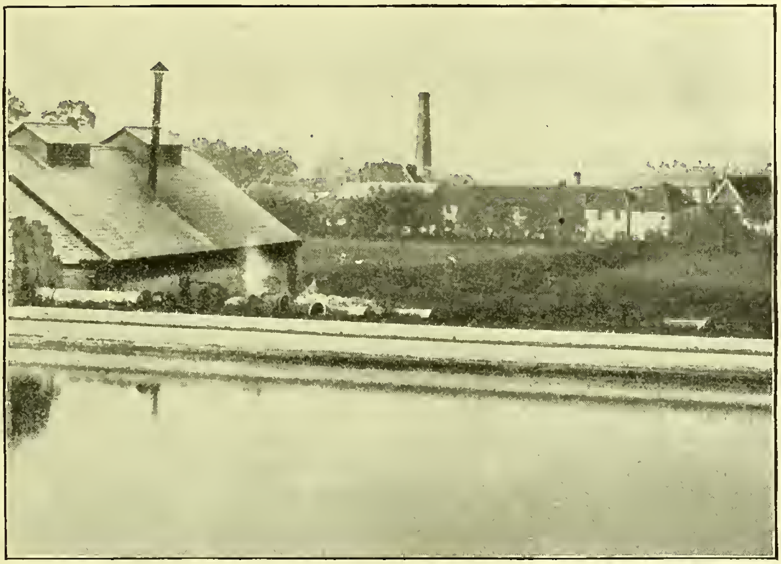


Fig. 20.—View of Sewage Farm at Wimbledon, England, with Precipitation Tank in Foreground; the Fields are Occasionally Used for Irrigation.

did the farms cause any nuisance, and that the neighboring property was not depreciated in value." *

In the discussion of Mr. Allen's paper on Sewage Disposal, read before the American Society of Civil Engineers, in 1888, the question of the production of bad odors from sewage farms was discussed, and a number of American engineers who had examined the English and other foreign sewage farms gave their experience on this point at length. The discussion is too long to quote here. Its chief interest centres in the pertinent illustration which it affords of the widely varying views which different people will obtain of the same question.†

* Rept. of Eliot C. Clarke to Mass. Drain. Com. (1885), p. 128.

† Trans. Am. Soc. C. E., vol. xvii., pp. 29-34.

In a paper read before the British Medical Association in 1888, Dr. Alfred Carpenter, of Croydon, England, who has for years watched closely the operation of the Beddington sewage farm, said:

(1) That the application of the sewage of a water-closet town to land in close proximity to dwelling-houses is not injurious to the health of the inhabitants of those houses provided the sewage be fresh; that it be applied in an intermittent manner, and the effluent be capable of rapid removal from the irrigated fields.

(2) The judicious application of sewage to soil of almost any kind, if it be mainly inorganic, will satisfactorily cleanse the effluent water, and fit it for discharge into

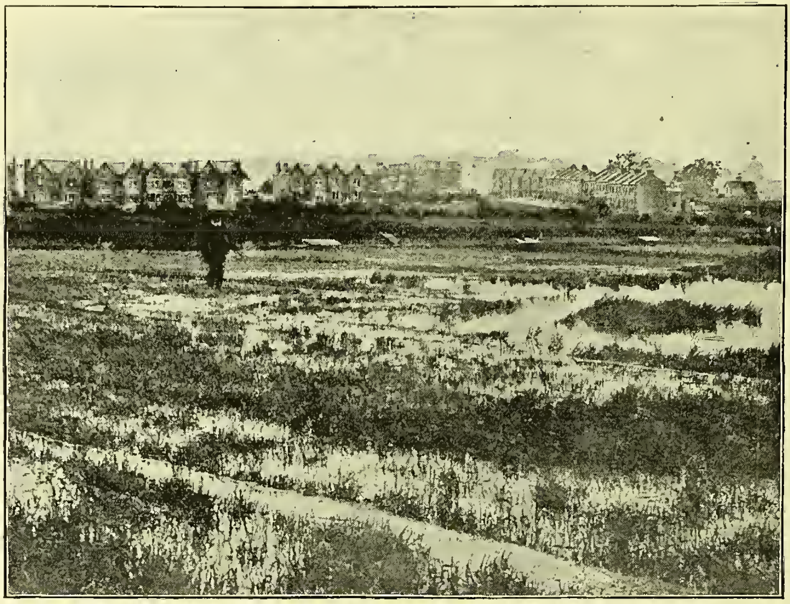


FIG. 21.—VIEW OF SEWAGE FILTRATION FIELDS, MITCHAM, ENGLAND.

any ordinary stream, provided the area treated is not less than an acre for each 250 persons.

(3) That vegetable products grown upon fields irrigated by sewage are satisfactory and safe as articles of food for both animals and man.

(4) That sewage farms, if properly managed, do not set up either parasitic or epidemic disease among those working on the farm or among the cattle fed upon its produce.

(5) That this immunity exists because the conditions necessary for the propagation and continuance of those disease germs which affect man and animals are absent; the microbic life on sewage farms being antagonistic to the life of disease germs, the latter, therefore, soon cease as such to exist.

(6) That sewage farms may be carried on in perfect safety close to populations. It is not, however, argued that the effluent water is safe to use for dietetic purposes.

(7) That there is an aspect in sewage farming which shows that it is a wise policy for the nation to encourage that form of utilization from a political economy point of view.

(8) That to be financially successful such farms require that the rainfall be

separated from the sewage; the area large enough for alternate cropping, and the capital employed sufficient to insure a continuous and rapid consumption of the crops produced.

(9) That, if practicable, sewage utilization by surface irrigation should be, for financial reasons, within the area of its own watershed and close to the populations producing the sewage; but it is not a necessity that it should be so, provided it be applied to the land within a few hours—not more than twelve—of its discharge, and that there is no arrest of movement for more than very short periods before it is so utilized.

From all the evidence now at hand it may be concluded that properly managed sewage farms will not render the neighborhood in which they are situated specially objectionable for residence by reason of the production of offensive effluvium nuisances.

Another question which is cognate to that of effluvium nuisance is in relation to the effect of sewage farming as a whole on health.

Obviously, if sewage farms are so managed as to prevent any serious pollution of the air in their neighborhood, one chief source of objection is removed. It is, however, possible that wells in the vicinity may be affected, though the arrangement of the underdrainage with reference to the natural direction of flow of the ground-water will reduce this danger to a minimum. When imperfectly purified sewage flows over the surface into streams some pollution may also result. For this latter, when a high degree of purity of effluent is essential, the proper remedy is to prepare area enough to insure the required degree of purity. With regard to the danger to wells, the Berlin sewage farm of about 19,000 acres may be cited, where a large population of laborers live permanently on the farm and draw their entire water supply from wells sunk wherever required throughout the fields. It is stated that no bad effects on health have thus far been observed. In the Report of the judges appointed by the Royal Agricultural Society in the sewage-farm competition already referred to, it is stated that "the results . . . show that sewage farming is not detrimental to life or health." A large amount of authoritative opinion substantiating this view can be quoted, but the foregoing may be deemed sufficient for the present purpose.*

* Probably the best example of successful sewage farms on a large scale are those of the city of Berlin, where about 19,000 acres have been purchased by the city for sewage irrigation. Of this area only about 11,000 acres had been used for sewage irrigation at the four original farms of Osdorf, Gross Beeren, Falkenberg, and Malchow to March 31, 1890. Sewage irrigation was begun at Osdorf in January, 1876; Gross Beeren in July, 1882; Falkenberg in March, 1879; and at Malchow in October, 1882. Additional areas not in use in 1890 have been purchased at Schenkendorf, Sputendorf, Klein Beeren, Blankenfelde and Hellersdorf. At the four original farms a portion of the area was still without special preparation in 1890, at which date about 8,000 acres had been specially prepared. The population of Berlin in December, 1890, was 1,578,790, whence the number of inhabitants per acre of specially prepared area was roundly 198. The quantity of sewage averages about 31 U. S. gallons per head of population per year. The special areas are added to from year to year.

The most complete account of the Berlin sewage farms in English engineering literature is that

There is, moreover, some reason for believing that well-managed sewage farms are not only not unhealthful to the neighborhood in which they are situated, but that they may be even in some degree the source of an increased healthfulness of the region immediately surrounding them. This apparently paradoxical conclusion is derived primarily from the statistics of mortality among those employed and living on sewage farms, from which it appears that sewage-farm laborers are as a class quite as healthful as a similar class elsewhere. The following figures in illustration of this point are from the report of the Judges in the sewage farm competition:

Name of farm.	Number of years in operation.	Persons employed or living on farm.	Children living on farm.	Number of deaths occurring.
Aldershot	15	25	12	0
Bedford	11	28	6	0
Birmingham	12	28	9	2 †
Croydon	18	94	30	5 ‡
Doncaster	6	44	22	0
Guisborough	9	8	4	0
Leamington	8	46	14	2
Reading	4	88 *	32	1
Wrexham	10	19	8	0
Totals	93	380	137	10

* These figures do not include the men engaged in laying out additional land for sewage purposes.
† These deaths occurred in connection with sewage tanks and not sewage farm.
‡ These deaths have occurred within the last 10 years.

As stated by the judges, "An examination of this table will show that the rate of mortality on an average of the number of years these farms have been in operation does not exceed 3 per annum."

If we consider that during the growing season the vegetation on a well-managed sewage farm is three or four times as luxuriant as in ordinary agricultural regions, we have a good explanation of why the irrigated areas are not necessarily more unhealthy than other similar agricultural regions without irrigation. The office of growing plants in converting carbon dioxide, on the one hand, into carbonaceous sub-

of H. A. Roechling, Assoc. M. Inst. C. E., as given in his paper, The Sewage Farms of Berlin, in Proc. Inst. C. E., vol. cix., Ses. 1891-92., Part III. Mr. Roechling has there presented the complete statistics and details of management of these extensive sewage farms. The paper came to hand too late to make extended extracts, but to give an idea of its contents the heads discussed are included as follows:

Area and General Statistics of Berlin; Sewerage of Berlin; Sewage Farms; Purchase of Sewage Farms; Distribution of the Sewage; Application of Sewage-water to the Land; Laying out of the Farms; Productive and Unproductive Acreage; Drainage of the Plats; Capital Expenditures on Farms; Management of the Farms; Labor on the Farms; Cattle kept on the Farms; Meteorological Conditions Prevailing on the Farms; Results Obtained from the Working of the Farms; Quantity of Sewage Treated on the Farms; Crops; Sewage Irrigation during the Winter Months; Letting of Sewage-treated Land; Harvest Returns; Financial Returns; Degree of Purification Attained; Comparison of the Berlin Results with those of English Sewage Farms; Alleged Liability of the Land to become Sewage-choked; Utilization of the Manurial Elements of Sewage; Quantity of Effluent Water; Sanitary Condition of the Berlin Sewage Farms.

stances (carbohydrates, etc.), which go to make up the structure of the plant, and, on the other, into free oxygen, which passes into the general stock in the atmosphere,* is well known. The increase in energy of these natural purifying agencies may be considered sufficient to render the quantity of oxygen in the air in the vicinity of sewage farms somewhat greater than in average agricultural districts; thereby counterbalancing any possible slight unhealthful tendency by reason of the presence of large quantities of sewage, some of which may be decomposing.

This view is further supported by the researches of Dr. Daubeny, late Professor of Botany, etc., at Oxford, who has shown that growing plants not merely evolve oxygen, but evolve it in the form of ozone.†

* Sachs' Physiology of Plants, Part III., Nutrition; Lecture XVII., Source of the Nitrogen in Growing Plants—Source of the Carbon; Lecture XVIII., Evolution of Oxygen, etc.

† Jour. Chem. Soc., Jan., 1867.

CHAPTER XIII.

ON SILOS AND THEIR USE IN SEWAGE FARMING.

The object of this chapter is to call attention to a system of preserving forage crops which is likely to materially influence the future development of sewage farming, and to indicate some of the sources from which more detailed information can be obtained.

Definition of Terms.

The terms silo, silage, and ensilage will be used, so far as the confusion which exists will permit, in accordance with the following definitions:

(1) Silo, the theoretically air-tight structure in which fodder is preserved.

(2) Silage, the fodder or material preserved in silos.

(3) Ensilage, the process of preservation.

How Silage is Produced.

In order to produce silage it is necessary to prepare a pit or chamber either in the ground, with a brick or stone impervious lining, or by building the same above the surface. The object to be gained is the depositing of the green crop in an air- and water-tight receptacle under conditions admitting of subjecting it to considerable pressure, by which nearly all the contained air is forced out. This is effected in a variety of ways, as: (1) By treading the green crop as it is deposited, and covering with a couple of feet of well-packed earth; (2) by constructing the silo with a movable covering arranged with chains and rollers for raising and lowering, which, after the crop is placed in the silo, is lowered and weighted to the extent of about 85 to 125 pounds per square foot of surface; (3) silage is sometimes made in stacks either in the open air or under sheds open at the sides, the partial decay of a portion of the material on the outside furnishing the necessary impervious coating. Salt is sometimes added as the crop is placed in the silo, to assist the process of preservation. Closed silos are kept sealed until opened for use.

Early Use of Silos.

In its original sense a silo was neither more nor less than a cellar used for storing grain, for which purpose underground pits have been used in eastern countries since a very early period, instead of placing it in granaries above ground. Such pits are stated to have been used by the nomadic tribes of Arabia, in order to prevent victorious enemies from obtaining possession of their food supplies. The Spaniards learned the art from the Moors, and in Spain it acquired a new use for the purely commercial object of storing up grain in times of plenty and low prices in order to preserve it to times of scarcity and high prices. From Spain the silo found its way into France and Germany, from whence its use finally extended to England and this country. *

The first record of the modern use of the silo in France is about 1820 and 1821, when the proprietor of an estate in the Puy de Dôme stored his grain harvested in those years in silos constructed for the purpose and kept it until 1828, when prices having risen to double the figure of seven years before, the silos were opened, and with the exception of a thin layer at the top the grain was found perfectly preserved.

The Modern Use of Silos.

The use of silos for preserving fodder crops has, however, grown up in England and this country mostly since about 1880.†

* A French work on agriculture, the first edition of which was published in 1600, contains the following description of what we now call the silo :

There remains for me to speak about another sort of granary, as novel as any I have seen, as there seems reason to disbelieve the experience of good found in their use. They are used in La Gascoyne and La Guyenne, where they employ these granaries more than in any other province of this kingdom. They are deep pits dug in the ground, called "*cros*," into which one descends with ladders for bringing in or carrying away the fodder, etc. Pliny considered such pits to be the best way of preserving corn, etc., as was practised in his time in Thrace, Cappadocia, Barbary, and Spain. Varro was also of his opinion, asserting that wheat can be kept sweet and entire 50 years, and millet 100 ; at the same time stating, so as to strengthen his opinion, that when Pompey the Great was sweeping the sea of pirates, there was found at Ambratia a large supply of beans (in good and sound condition), in a cavern where they had remained stored away since the time when King Pyrrhus was fighting in Italy, and nearly 120 years had then passed.

. . . .

In the edition of the same work of 1804 it is stated :

In 1707 there was discovered in the citadel of Metz a large quantity of corn, placed there in 1528, in one of the underground rooms, where it was so well preserved that the bread which was made from it, two centuries after it had been placed there, was found very good. There exists now (1804) at Andres, department of the Pas de Calais, one of these underground places made by the Romans.

† Professor J. F. W. Johnson described the German system of silos for sour fodder or sour grass in the Transactions of the Highland and Agricultural Society in 1843. His paper is a clear account of ensilage as practised at that time, and may be partly reproduced here as a useful contribution to the English literature of the subject.

A method has lately been tried in Germauy, which, by the aid of a little salt, seems in a great measure to attain this object (i.e., to preserve the feeding properties of grass more completely than by the process of haymaking). Pits are dug in the earth from 10 to 12 feet square, and as many deep ; these are lined with wood, and puddled below and at the sides with clay. They may obviously be made of any other suitable dimensions, and may be lined with brick. Into this pit the

In Hungary, sour grass has been in use for many generations, but the modern practice of preserving green fodder as sweet silage appears to have been used there for only about the last 40 years. In Germany Herr Reihlen, of Stuttgart, described his appliances in 1862; while in France the use of the silo for preserving green fodder apparently dates from 1870, although, as stated above, used long before that time for preserving grain.*

THE VALUE OF ENSILAGE IN SEWAGE FARMING.

The chief value of the process of ensilage in its application to sewage farming lies in the fact that the large forage crops which are produced by sewage irrigation may be successfully preserved for feeding during the winter, especially in wet seasons, when the making of hay is more difficult than in dry. A succession of wet seasons in England

green crop of grass, clover, or vetches is put just as it is cut. Four or 5 cwts. are introduced at a time, sprinkled with salt at the rate of 1 lb. to each cwt., and if the weather and consequently the crop be dry, two or three quarts of water to each cwt. should be sprinkled over every successive layer. It is only when rain or a heavy dew has fallen before mowing that, in East Prussia, this watering is considered unnecessary. Much, however, must depend upon the succulency of the crop. Each layer of 4 or 5 cwts., as spread evenly over the bottom, is well trodden down by five or six men, and, especially, is rammed as close as possible at the sides with the aid of wooden rammers. Each layer is thus salted, watered if necessary, and trodden in succession till the pit is perfectly full. Much depends upon the perfect treading of the grass for the exclusion of the air, and, therefore, for a pit of 10 feet square, 4 cwts. are as much as ought to be put in for each layer. Between each layer may be strewed a few handfuls of straw, in order that, when emptying the pit afterwards for the daily consumption of the stock, the quantity taken out may be known without the necessity of a second weighing. When the pit is full, the topmost layer is well salted, the whole then covered with boards or a well-fitting lid, and upon these a foot and a half of earth, for the more perfect exclusion of the air. A pit 10 feet square, and as many deep, will hold about 5 tons of fresh grass, and each pit should, if possible, be filled in not less than two days.

When covered up, the grass speedily heats and ferments, and after the lapse of about six days, when the fermentation has ceased, the whole has sunk to about one-half of its original bulk. The lid must be examined during the fermentation at least once a day, and the earth, as it sinks, carefully replaced wherever crevices appear; for, if the air be allowed to gain admission, a putrefactive fermentation will come on, which will impart a disagreeable odor to the fodder, though it will not prevent it from being readily eaten by the stock. When the first fermentation has ceased, the lid may be removed, the pit again filled with fresh grass, trodden in, salted, and covered as before. A pit 10 feet square, when perfectly full of this fermented grass, will contain nearly 10 tons—equal to 2 or 3 tons of dry hay. The grass, when thus fermented, *has the appearance of having been boiled*, has a sharp acid taste, and is greedily eaten by the cattle. The pits should be kept covered for at least six weeks, after which they may be opened successively as they are required, and may be kept open till their contents are consumed by the cattle without suffering any injury from the contact of the atmospheric air. Of the feeding qualities of this salted fodder, one experimenter says that, by giving only 20 lbs. a day of it, along with chopped straw, he kept his cows in condition during the whole winter. His green crop was vetches, and the twenty pounds of salted fodder were equal to or would have made less than four pounds of vetch hay. Another experimenter says that on a daily allowance of 28 lbs. of his salted fodder his cows gave a rich and well-tasted milk.

This method of salting and preserving green crops in their moist state appears to afford an answer to the first question which is naturally asked when we are told of the difference in feeding value between the same grass when first cut and when dried into hay. It is probable that the fermentation which takes place in the pit may in some degree diminish the nutritive value of the grass, but the likelihood which exists that a very large proportion of this value will be retained renders the method of salting in this manner well worthy the attention of our more skilful agriculturists. It would greatly benefit both theory and practice also were careful series of experiments to be made in different localities, with the view of determining the true relative value in feeding of stock of the grass of the same field when newly cut and when salted and preserved in the manner above described.

* The foregoing account of the early history of the use of silos is abstracted from a Report on the Practice of Ensilage at Home and Abroad, in the Jour. of the Roy. Ag. Soc. of Eng., vol. xx., sec. ser., p. 126. By H. M. Jenkins, Sec. of the Soc.

during the last few years, where the practice of ensilage is very common, have demonstrated that even when made in open stacks the forage, by taking the proper precautions, can be quite successfully preserved.*

Ensilage in the United States.

Having given in the preceding paragraphs some of the main facts in the early history of ensilage, we may now consider the present state of the art as it exists in the United States. A number of the Agricultural Experiment Stations have experimented on the various methods of preserving forage in silos which have been proposed, and conducted various investigations as to the philosophy of the process and the best methods of using it in our climate.

At the Illinois Agricultural Experiment Station, Professor T. J. Burrill has studied the biology of the process in considerable detail. His paper thereon may be consulted for a good presentation of the present views in regard to the changes taking place in the silo, but its length precludes giving more than the summary as follows : †

Ensilage is a very variable product. The variations are due to so many factors—including differences in the original material, in the states and conditions of the weather, and in the construction of the storage bins—that great care and much knowledge must be required to secure reasonably uniform results.

Ensilage is never truly preserved fodder, but is more nearly such when the mass has been very hot for a time and then has the air most thoroughly excluded by the proper construction of the silo and the densest attainable condition of the material. The initial high temperature is probably mostly serviceable by causing this closer packing of the mass rather than by killing the germs or other ferments.

No appreciable alcoholic fermentation occurs. The very high temperature often attained is due to two or more species of rod-like bacilli, which appear to cause butyric fermentation and its allies.

Lactic fermentation is most abundant in the earlier transformations of ensilage not originally rising to a high temperature.

Acetic fermentation only occurs when the temperature sinks below 35° C. (95 F.). A large proportion of water is favorable to this change, and the sharply acid material is much less likely to be attacked by decomposing agents (other bacteria and mould fungi). Except for the difference in density of the material, that originally hot subsequently sours nearly as rapidly as that less heated at first.

The best results are obtained by the most nearly perfect exclusion of air. For this purpose uniform distribution upon filling the silo is of more importance than persistent tramping, because the pressure of the mass must be mostly relied upon.

Sources of Information.

In regard to the construction of silos, the paper in the Journal of the Royal Agricultural Society for 1884 contains descriptions of

* Experiments in Making Ensilage during the Wet Season of 1888. Jour. Roy. Ag. Soc. of Eng., vol. xxv., sec. ser., p. 280. By H. Kains-Jackson.

† The Biology of Ensilage. By T. J. Burrill. Bull. No. 7, Nov., 1889, Univ. Ill. Ag. Ex. Sta

nearly every form of silo that has been used abroad. The matter is there treated under the following heads:

(I.) Silo without roof.
(II.) Roofed silos with portable weights.
- *a.* Silage unchopped.
- *b.* Silage partly chopped.
- *c.* Silage entirely chopped.

(III.) Silos with mechanical means of compression.
(IV.) Foreign silos.
- *a.* France.
- *b.* The Netherlands.

The author of the paper states that he has refrained from giving details of American practice, in consequence of differences in climate rendering it an uncertain guide to English farmers. It is clear, however, in the light of the more extended experience of the present day, that generally the results of English and French practice are applicable here, and the paper may be accordingly referred to for excellent illustrations of many useful forms of silos.

The construction of silos has, however, been discussed at length during the last 8 to 10 years in nearly all the American agricultural journals, and experiments as to the best form for American conditions made by some of the Agricultural Experiment Stations. A reference to the bulletins of the several stations, and Reports of State Boards of Agriculture, will furnish the necessary information to anyone proposing to build silos, or in pursuit of information in regard to the use of silage for feeding stock.*

Experiments with Rye-grass.

In the chapter on Broad Irrigation it was remarked that one chief difficulty in the way of making sewage farming return a commercial profit has thus far been the impossibility of preserving the large forage crops of Italian rye-grass for use in winter. Experiments have been made in England in reference to preserving the rye-grass in silos, with the result of indicating that superior silage may be made from rye-grass by this process. Further, the ease with which corn forage crops may be grown after ordinary grain crops are harvested in July,

* The following Reports and Bulletins of the Agricultural Experiment Stations, Agricultural Boards, etc., may be consulted :

(1) Illinois (University of) Ag. Ex. Sta., Bull. No. 2, Aug., 1888. Ensilage. By Thomas J. Hunt. Gives an account of the filling of a silo, with statement of conditions of contents when opened 6½ months after filling, with feeding experiments, etc. 10 pp.

(2) Maine (State College) Ag. Ex. Sta., An. Rept. for 1889. Discusses composition of silage; digestible matter of, compared with hay; digestibility of, compared with corn fodder, etc., pp. 46–80.

(3) Michigan Board of Agriculture Reports for the years 1885, 1887, 1888, 1889, and 1890.

In the 24th An. Rept (1885) is given an account of experiments with "ensilage" made in 1881–2

and forced forward during the warm weather of that month and August and the early part of September by judicious sewage irrigation, and when mature preserved by ensilage, gives sewage irrigation

and 1882–3, including cost of constructing silo, feeding same, etc., with results of feeding experiments, pp. 100–120.

In the 26th An. Rept. (1887) is given a discussion on Ensilage at the Fremont Institute, Feb. 3, 1887, pp. 379–382.

In the 27th An. Rept. (1888) information is given in regard to cost of new silo built at the college farm the previous year, etc.

In the 28th An. Rept. (1889) under the head Silos and Ensilage the following special points are discussed:

I. Seven years' experience with Silos and Ensilage at the College Farm.
II. Views of Prominent farmers of Michigan on Ensilage.
III. Experiments with Ensilage vs. Corn harvested in the ordinary manner.
IV. Comparative test of varieties of Ensilage Corn.
V. Forage plants, Lucerne. On hard grass. Pp. 252–272. (Reprint of Bull. No. 47.)

The chemical composition of ensilaged corn is given in Bull. No. 49, reprinted in An. Rept., pp. 296–300.

Professor A. J. Cook also discusses "Silo and Ensilage" in the Report, being a lecture at the Centreville Institute, Feb. 19, 1889.

In the 29th An. Rept. (1890) Professor A. J. Cook contributes a paper, The Silo, in which the main heads are:

I. Importance of the Silo.
II. The best crop for Silage.
III. How shall we plant?
IV. Location of the Silo.
V. Building a Silo.
VI. Size of the Silo. Pp. 420–424.

In the same Rept., pp. 136–138, Dr. R. C. Kedzie presents tabulated analyses showing the changes which take place in the silo.

(4) Minnesota (University of) Ag. Ex. Sta., Bull. No. 8 (July, 1889). Short account of an experiment in ensilaging clover.

(5) New Hampshire Ag. Ex. Sta., Bull. No. 1 (April, 1888), on "Ensilage." Bull. No. 3 (July, 1888), "Ensilage" in Dairy Farming.

(6) New York State Ag. Sta. at Geneva, An. Reports for 1885, 1887, 1888, 1889, 1890.

The 6th and 7th An. Reports, 1887 and 1888, contain an account of a successful experiment in preserving Silage in the open air. (6th Rept. pp. 73–75. 7th Rept. pp. 326–330.)

Analyses and results of experiments on digestibility of silage are given in the 8th An. Rept. (1889), pp. 93–94.

A number of comparative feeding experiments are given in the 9th An. Rept. (1890).

(7) Pennsylvania State College Ag. Ex. Sta. Reports for 1889 and 1890, contain the results of a number of comparative experiments. See Rept. for 1889, "Comparison of Ensilage and Field-Curing for Indian Corn," pp. 113–137; Rept. for 1890, "Ensilage and the Corn Crop," pp. 43–123; Bull. No. 9 (Oct., 1889), on Digestibility of Corn Fodder and Silage, may be also consulted.

(8) Vermont 11th An. Rept. State Bd. Agriculture, 1889–90, "Corn Fodder and Ensilage." By Homer W. Vail, pp. 251–324. See also 3d and 4th An. Repts. State Ag. Ex. Sta., 1889 and 1890.

(9) Wisconsin Ag. Ex. Sta., 6th and 7th An. Repts. (1889 and 1890). In the 6th An. Rept. (1889), "Experiments with Fodder Corn and Ensilage," pp. 123–145. In 7th An. Rept. (1890), "Corn Silage vs. Dry Fodder Corn for Milk and Butter Production," pp. 80–97; also "Comparison of Siloing and Field-Curing of Indian Corn," pp. 215–237.

Bull. No. 28 (July, 1891), "The Construction of Silos," may be consulted for many details of recent silo construction in this country.

The foregoing list of recent American literature of the silo and process of making silage makes no claim to completeness. It merely represents what the authors have been able to get together without special effort. The subject is discussed in several reports and bulletins of the Agricultural Experiment Stations not referred to here. In addition a number of special treatises have been published.

farmers a command of the situation which they have not previously had. The following from the paper in the Journal of the Royal Agricultural Society of England, from which we have already quoted, will serve to show the certainty with which even the rye-grass may be made into silage.*

> The silo is 14 feet long, 13 feet deep, and 6 feet wide, and is above ground, being constructed of 14-inch brick-work with a floor of 5-inch cement concrete, in the end of a barn. Its cost was about 18*l.* 4*s.* 3*d.* ($92), and it will last probably as long as we can look forward to. It was filled in July, and we purpose beginning again in June, 1884.
>
> The pitted material was sewaged Italian rye-grass, about 4½ acres, and when cut to put in the silo was more than ripe. It was chopped into ¾ of an inch lengths by steam, Maynard's chaff-cutter being used. Salt was added only to preserve it.
>
> The silo was filled in two days of 5 hours each, and every layer of about six inches was well rammed, 22 lbs. of salt being added to each. The fodder was covered with boards closely placed and weighted with bags of sand; no mechanical contrivance was used.
>
> The silo contains from 10 to 12 tons fit for use. The covering with old waste boards and sand cost about 2*l.*, and the expense of filling was 5*l.* 3*s.* 6*d.*
>
> . . . .
>
> By this system the land can be cleared much quicker, cheaper, and with less waste than by trying to make sewage-grass into hay. Indeed, for two or three years, we have found it impossible to get such Italian rye-grass dry enough to prevent it destroying itself by heat, on account of the juices and fat contained in the grass. With regard to keeping qualities, as this is the first silo we have filled, we can only say that we opened it on December 18, 1883, and have continued using some of it every day since then up to this date, 11th January, 1884, and it is not injuriously affected by the atmosphere being let into it. Horses, cattle, and sheep eat the silage from the silo with great avidity, and I should think from the little experience I have had in feeding with silage it is best and most effective and valuable when mixed with straw, or corn-chaff, or any other ordinary food that requires something to increase its feeding value and make it palatable.

In regard to the quality of the rye-grass silage the author of the report states that on account of the interest attaching to this attempt to preserve sewage-grass by means of ensilage, he visited the silo in question on December 18, 1883. Evidently the grass had been allowed to get dead-ripe before filling, and the consequence was that the silage was singularly dry. Fermentation had, however, taken place, but there was a considerable amount of mould near the outside wall. A sample taken from the interior on January 2, 1884, was found to contain only 55 per cent. of water. This sample, both in a box and bottle, was still perfectly good in the middle of March, retaining to the full its aroma. Mr. Jenkins ventures the opinion that the result of this experiment is very encouraging, and suggests a better outlook for sewage farms.

Experiments on making silage from rye-grass and on the feeding of cattle with the same have been conducted at the Crewe (England) sewage farm, with the result that the increase in weight of cattle fed on silage for a given time was considerably in excess of the increase of weight in those fed on hay alone for the same length of time.

* From description of silo, etc., of Mr. Garrett Taylor, Rept. on Practice of Ensilage at Home and Abroad, *loc. cit.* pp. 187–188.

CHAPTER XIV.

INTERMITTENT FILTRATION.

Origin of Intermittent Filtration.

The first mention of intermittent downward filtration, as a process of sewage purification, to be found anywhere, is in the First Report of the Rivers Pollution Commission, made in 1870, where is recorded a series of experiments on the filtering capacity of different soils as carried out in the laboratory of the Commission.*

In discussing intermittent filtration the Commissioners say that the purification of sewage by filtration through sand, gravel, chalk, or certain kinds of soil, if properly carried out, is the most effective means for the purification of sewage of any to which reference has been made (in their report); it is further stated that irrigation owes no inconsiderable amount of its success to the contemporaneous effect of the filtration of the sewage through the soil of the irrigated fields. These statements seem trite enough now, although in 1870 they were somewhat in advance of the current views on the subject.

The Commissioners begin their discussion by an account of some experiments on the continuous *upward* filtration of sewage through sand, and conclude that that form of filtration "is inefficient in the purification of sewage from soluble offensive matters." These experiments also showed that nitrification took place only so long as the pores of the sand still contained the air with which they were filled at the beginning of the experiment.

Experiments were also made upon various kinds of material with the sewage flowing intermittently down through the same; hence intermittent downward filtration in contradistinction to continuous upward filtration. In the first place the effect of downward filtration through 15 feet (1) of sand, and (2) of sand and chalk was determined, after which the effect of filtration through about 5 to 6 feet of different soils was studied. In these latter experiments the first soil tried was a very porous gravel taken from the field at Beddington, near Croydon, which had been under sewage irrigation for five years. This soil gave a satisfactory purification when filtering at the rate of 7.6 Imperial, or about 9.1 U. S. gallons of sewage per cubic yard of filtering material

* 1st Rept. Riv. Pol. Com., pp. 60–70. Also see p. 128 of same report.

per diem; but when the rate was doubled nitrification ceased, the pores of the soil becoming blocked up so that they would no longer transmit the whole volume of sewage supplied and also afford time for aëration. Analyses showing the degree of purification reached with different quantities of sewage applied are given in the report.

Various other soils were experimented upon at length, but the results now have historical value, chiefly.

Definition of Intermittent Filtration.

Rather singularly the Rivers Pollution Commission, while originating intermittent downward filtration, did not propose a complete definition of it as a process of sewage purification. This deficiency is, however, fully supplied by the Royal Commissioners on Metropolitan Sewage Discharge, who define the difference between broad irrigation and intermittent filtration as follows: *

> Broad irrigation means the distribution of sewage over a large surface of ordinary agricultural ground, having in view a maximum growth of vegetation (consistently with due purification) for the amount of sewage supplied. Filtration means the concentration of sewage at short intervals, on an area of specially chosen porous ground, as *small* as will absorb and cleanse it; not excluding vegetation, but making the produce of secondary importance. The intermittency of application is a *sine qua non* even in suitably constituted soils, wherever complete success is aimed at.

The Theory of Intermittent Filtration.

The foregoing definition, while sufficiently comprehensive for a working statement of what intermittent filtration is, can hardly be considered applicable in the broader sense of how the purification of sewage is effected through its means. This we have already seen is through the agency of nitrification; but in order to obtain a clear idea of how nitrification proceeds in the filter we may consider the theory of intermittent filtration from different points of view a little in detail, using as a basis for this purpose the discussion in the Massachusetts Special Report, Part II., pp. 859–862, and further information from the report of the Massachusetts State Board of Health for 1891, p. 425 *et seq.* The working of a filter may be considered as explained in three ways, namely, that its action is either mechanical, chemical, or biological. The old view was that filters are merely strainers; this is so familiar that the word filter has come to mean ordinarily a more or less perfect strainer. This, however, cannot apply to intermittent filtration. An area of sandy soil may, it is true, be a very effective strainer, but if worked intermittently it is much more than this. A strainer soon chokes and must be cleaned, but an intermittent filter

* Sec. Rept. (1885) p. 46.

has, in a large degree, self-cleaning properties, a phenomenon actually shown at the Lawrence Experiment Station, where, after over four years of use, the material of some of the filters was still clean enough to do good service, although the 1891 report states that organic matter does accumulate in the filtering tanks, so that probably some artificial aid to cleansing must eventually be employed. The results of analysis and a comparison of the chemical composition of the Lawrence affluent with that of the effluent disproves the mechanical theory of the filter's action. There is, indeed, in the life-history of an intermittent filter a period at the very beginning when the purification is but little if anything more than mechanical, but under the best conditions there speedily begins a change of the profoundest significance. The dissolved organic matters no longer pass out as they came in. The suspended matters, mostly cease to accumulate; both appear in the effluent under other forms. Mechanical processes alone could not effect the changes which occur under conditions excluding the purely mechanical hypothesis.

A striking example is to be found in the operation of Tank 16 A, as described at pages 563–567 of the Special Report, Part II. This tank is composed of small stone, the spaces between which are, as compared with much of the organic matter of sewage, of infinitely large size; yet the changes wrought by this filter are far more extensive, the purification far more complete, than in filters of peat or garden soil, which are mechanically nearly perfect strainers. It would be hard to find a better example of the possibilities of sewage filtration than this tank supplies, yet it testifies in the clearest manner to the absolute insignificance of any merely mechanical factor in the purification of sewage by intermittent filtration.

The theory that the action of the filter is fundamentally chemical is much more reasonable. The powers of intermittent filters to effect chemical changes are abundantly testified to by the detailed investigation recorded in the Massachusetts Special Reports. Moreover, the transformations effected are so thorough that purification by fire readily occurs as an analogous transformation which is purely chemical in its operation. The view, however, that an additional factor in intermittent filtration must exist, was recognized at the very beginning of experiments upon intermittent filtration. Thus Frankland, although insisting, in his original discussion in the first report of the Rivers Pollution Commission, upon the chemical character of the purification obtained, referred to the process as an act of respiration, adding, almost unconsciously, the vital to the purely chemical idea. Frankland says:

From all these experiments, then, it appears that the action of the filter must not be considered as merely mechanical. The process carried on in it is also chemical. Filtration, properly conducted, results in the oxidation and transformation of offen-

sive organic substances in solution, as well as in the mere mechanical separation of the suspended solid matters which, when in motion, sewage conveys with it. If the process could be carried one step further, and those harmless inorganic salts, which are carried off by the effluent water of a perfect sewage filter, in too dilute a solution to be profitably extracted, could be converted into something positively useful, the remedy would be complete. We should have succeeded in not only abating an injurious nuisance, but in realizing a product which would help to refund expenses. This further step is possible in the great majority of cases, and it is to the plan of using sewage in irrigation, as being in reality a filtration of the best kind, *plus* a conversion of its filthy contents into valuable products, that we have now to direct attention. . . .

But a filter, as has been already shown, is not a mere mechanical contrivance. It is a machine for oxidizing, and thus altogether transforming, as well as for merely separating the filth of dirty water. And in this respect especially irrigation necessarily includes filtration. Sewage traversing the soil undergoes a process to some extent analogous to that experienced by blood passing through the lungs in the act of breathing. *A field of porous soil irrigated intermittently virtually performs an act of respiration, copying on an enormous scale the lung action of a breathing animal; for it is alternately receiving and expiring air, and thus dealing as an oxidizing agent with the filthy fluid which is trickling through it. And a whole acre of soil,* 3 *or* 4 *feet deep, presenting within it such an enormous lung surface, must be far superior as an oxidizer, for dealing with the drainage of* 100 *people, to any filter that could be practically worked for this purpose.**

To this item in the character of both irrigation and filtration as chemical processes there must be added another cleansing agency, also of a chemical kind, in which the former has very greatly the advantage. We refer to the actual appetite for certain dissolved impurities in filthy water which soil, whether in a tank or covering a field, owes both to general surface attraction and to the chemical affinities which some of its ingredients possess. This appetite is doubtless very limited in its amount, but it is directly proportional to the quantity of material exercising it. The superior capability of this kind which the soil of a field possesses, in comparison with that in a limited filtration tank, depends partly on the immensely greater quantity of cleansing material which an acre drained perhaps 4 feet deep necessarily brings to bear upon the filthy fluid; but also and especially on the fact that in the former case this is, except in winter time, always kept alive and fresh by the action of plant growth in constantly removing the deposited impurities, and rebuilding them into wholesome organic structures.

We see, then, that Dr. Frankland, although strenuously insisting upon the chemical nature of the purification obtained in intermittent filtration, nevertheless, in the portion which we have italicized, defined conditions which we now know can only be satisfied by assuming that micro-organisms are an indispensable element in the constitution of a successful intermittent filter, hence the final view is that the operation of such a filter is essentially biological rather than either mechanical or chemical.

Biological phenomena, however, depend upon chemical phenomena, and in order that Dr. Frankland's act of respiration can take place, the presence of a small but sufficient quantity of free oxygen is indispensable. This is well established by the experiment upon Filter Tank No. 14, as detailed at pages 144, 160, 730, and 734 of the Massachusetts Special Report, Part II. Again, the biological theory demands the presence and activity of living micro-organisms. In the chapter on

*As enforcing this point refer to Tables 37-41 B in Chapter VIII., pp. 164-168.

Nitrification and the Nitrifying Organism, we have detailed some of the difficulties which have been met by biologists in their endeavors to isolate and identify the particular kinds which appear indispensable to the process of nitrification; and although the problem has been hedged about by extraordinary difficulties it is believed that the essential organism of nitrification has been successfully isolated. The chief points established are: (1) That the best results are obtained in filters which are mature, and have thus become adapted to their work; (2) that a distinct regimen is essential to success; (3) that free oxygen is indispensable; (4) that the sewage is best purified when held in thin films upon or between sand grains and gravel stones; and (5) that the period of greatest destruction of the ordinary sewage bacteria corresponds closely with the time of most active nitrification.

The experiments on intermittent filtration which the Massachusetts State Board of Health has carried out in the last four years, from which the foregoing views as to the present understanding of the theory of intermittent filtration are drawn, are the most extensive that have ever been made.*

In the Nineteenth Annual Report, at page 43, the Massachusetts State Board describes the arrangements at the experimental station at Lawrence, and gives in detail the method of preparing the material in the several large tanks used in the experiments.

The New Thesis of Intermittent Filtration.

In the Twentieth Annual Report, page 32, the Board gives some of the results of the first year's work and states the new thesis of intermittent filtration, namely: (1) That sewage can be more efficiently filtered through open sand than through sand covered with soil; and (2) that the upper layers of intermittent filtration areas should be composed of open sand, through which the sewage will rapidly disappear, leaving room for air to enter and come in contact with the thin laminæ of liquid covering the particles of sand.

In the Special Report, Part II. (1890), on the Purification of Sewage and Water, etc., the results of two years' work in the filtration of sewage through various grades of sand are discussed in detail generally, by Hiram F. Mills, C.E., while the biological results are discussed by

* Professor Henry Robinson, whose right to speak with authority will be conceded, in a paper on Sewage Disposal with reference to River Pollution and Water Supply, read in 1891 at the London Congress of Hygiene and Demography, said:

> The action that has been taken by the State Board of Health of Massachusetts, to protect the purity of inland waters, deserves to be specially commended as an example of broad and wise policy in instituting the systematic investigation by engineers, chemists, and biologists of all that bears upon the purification of sewage and on the filtration of water. . . . The exhaustive reports under these different heads may be fairly stated to be far in advance of anything that has been fairly attempted in this country (England).

Professor Wm. T. Sedgwick and his assistants. Nearly every possible phase of sewage purification by filtration is touched upon, and whoever would compass the subject as it stands to-day must study the original report, and also its continuation in the Annual Report of the Massachusetts State Board of Health for 1891. Without going extensively into the detail here, we will present a brief digest of some of the

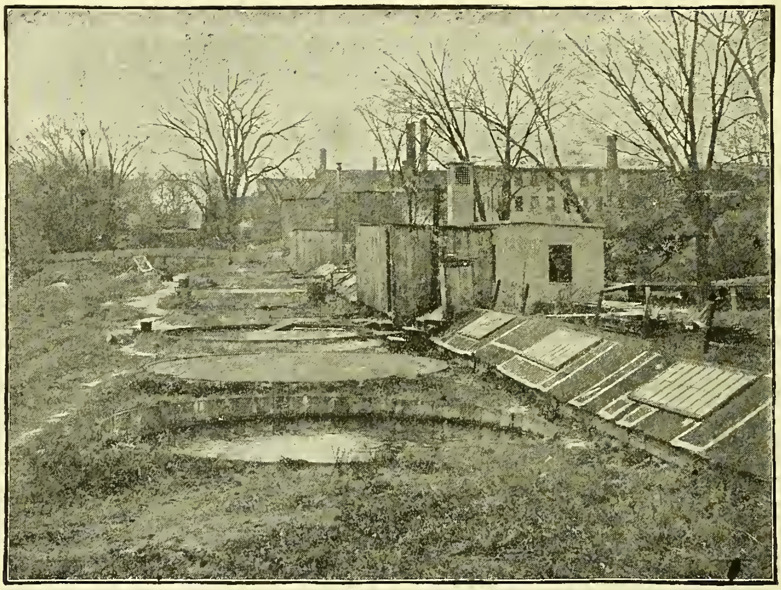


FIG. 22.—VIEW OF LARGE TANKS AT THE LAWRENCE EXPERIMENT STATION.

results, together with a summary, the same as already done for the work on chemical purification. The large experimental tanks used at Lawrence are shown by Fig. 22.

RESULTS WITH TANK NO. 1.

In the chapter On Nitrification and the Nitrifying Organism the main points in the theory of nitrification of organic substances have been set forth. From various studies made abroad it had been concluded that nitrification was almost entirely a summer process, which nearly ceased on the approach of cold weather. The Lawrence experiments, however, show that by due attention to details a fairly efficient nitrification may be obtained in winter as illustrated by Table No. 58, giving the results of nitrification in Tank No. 1, the filtering material in which is "five feet in depth, of very coarse, clean mortar sand taken from a depth of six or eight feet."

In studying the results embodied in Table No. 58, it is important to remember that the percentage of nitrification attained during any given period does not represent the total amount of nitrogen removed. The experiments indicate that sand filters have considerable capacity for storing the nitrogenous matter at one period and later on converting it into nitrates. There is also a considerable loss of nitrogen, or, at any rate, a considerable portion which does not appear in the effluent, but which has been clearly removed as determined by complete analy-

TABLE No. 58.—PERCENTAGE OF NITROGEN APPLIED IN THE SEWAGE THAT APPEARS IN THE EFFLUENT AS NITRATES.

Date.	Nitrogen applied in sewage.	Nitrates in effluent corrected for quantity.	Per cent. of applied nitrogen.	Average daily quantity, gallons.	Temperature, F°.	
					Sewage.	Effluent.
1888.						
May	3.0238	1.974	65	156*	47	52
June	1.7568	0.879	50	217	63	64
July	2.0247	1.040	51	283	69	71
August	3.9618	1.319	33	303	72	73
September	4.8287	1.021	21	325	69	68
October	2.4970	1.096	44	313	49	55
November	2.3837	1.125	47	304	45	49
December	1.4652	0.794	54	288	45	41
1889.						
January	1.4772	0.737	50	283	45	40
February	1.4864	0.797	54	290	45	38
March	2.0855	1.148	55	294	37	38
April	2.4395	1.968	81	299	45	46
May	2.3517	2.125	90	262	60	59
June	2.9514	1.842	62	243	66	66
July	3.1160	1.785	57	293	72	70
August	2.5490	2.024	79	287	71	69
September	3.2989	1.470	45	286	68	67
October	2.9411	1.595	54	293	53	56

* Tank No. 1 has an area of one two-hundredths of an acre.

TABLE No. 59.—NUMBER OF BACTERIA FOUND IN THE SEWAGE APPLIED TO THE COARSE SAND FILTER TANK No. 1 AND IN THE EFFLUENT THEREFROM ON GIVEN DATES, TOGETHER WITH THE AMOUNT APPLIED, AMOUNT OF EFFLUENT, AND THE TEMPERATURE OF SEWAGE AND EFFLUENT.

Date.	Quantity applied, gallons per acre per day.	Quantity of effluent, gallons per acre per day.	Bacteria in :		Temperature, F°.	
			Sewage, per c.c.	Effluent, per c.c.	Sewage.	Effluent.
1888						
October 2	60,000	79,400	167,327	2,122	53	61
" 11	60,000	56,800	313,420	88	49	57
" 25	60,000	62,000	840,000	110	45	51
November 28	60,000	64,200	1,762,950	3,799	44	34
December 21	60,000	53,800	409,500	27	46	40
1889						
January 2	120,000	117,600	355,000	11,020	45	40
February 19	60,000	57,200	137,550	30	44	38
March 12	60,000	59,000	251,300	66	33	37
April 16	60,000	54,600	3,963,000	74	46	46
May 14	60,000	60,000	1,679,200	37	64	59
June 18	120,000	97,800	653,800	146	69	67

TABLE No. 60.—MINERAL ANALYSIS OF SAMPLES OF SEWAGE APPLIED TO TANK No. 1 AND OF ITS EFFLUENT.

(Parts per 100,000 of the original liquid.)

	Sewage, Dec. 11, 1888.	Effluent, Dec. 15, 1888.		Sewage, Dec. 11, 1888.	Effluent, Dec. 11, 1888.
Total solids	48.4	24.6	Aluminium oxide	0.17	0.18
Loss on ignition	18.6	1.6	Ferric oxide	0.01	0.01
Fixed residue	29.8	23.0	Manganic oxide	0.56	...
Sodium oxide	5.18	5.24	Nitrogen as nitrate	....	0.70
Potassium oxide	1.96	1.46	Chlorine	4.98	4.56
Calcium oxide	3.36	2.98	Sulphuric acid	1.57	2.11
Magnesium oxide	0.84	0.86	Silica	1.86	1.42
These substances may be combined as follows:					
Potassium nitrate	....	3.04	Magnesium carbonate	1.76	0.48
Potassium chloride	3.10	....	Calcium carbonate	6.00	5.32
Sodium chloride	5.76	5.69	Alumina	0.17	0.18
Sodium nitrate	....	1.61	Ferric oxide	0.01	0.01
Sodium sulphate	2.28	3.74	Manganic oxide	0.56	....
Sodium carbonate	1.52	....	Silica	1.86	1.42
Magnesium chloride	....	1.49			

sis of the crude sewage. This phase of the subject is farther illustrated by Tables Nos. 61 and 62 following.

The results of purifying sewage with coarse sand filters, so far as nitrification is concerned, is exhibited by Table No. 58, and inasmuch as such filters possess some advantages over those of finer sand, we may consider their construction a little in detail.

In the first place, it has already been indicated that in all soil purification nitrification plays a leading part in resolving the objectionable organic constituents of sewage into inert and harmless inorganic compounds. A study of sewage purification by means of intermittent filtration is therefore in reality mostly a study of the process of nitrifi-

TABLE No. 61.—PERCENTAGE OF THE AMMONIAS IN THE CRUDE SEWAGE APPLIED TO TANK No. 1, WHICH APPEARED IN THE EFFLUENT, IN COMPARISON WITH THE PERCENTAGE OF THE TOTAL NITROGEN IN THE EFFLUENT FOR THE MONTHS INDICATED, ETC.

Month.	Percentage of the ammonias of the sewage, appearing in the effluent.						Percentage of total nitrogen of the sewage appearing in the effluent.	
	Free.		Albuminoid.		Sum.			
	1888.	1889.	1888.	1889.	1888.	1889.	1888.	1889.
May	4.8	2.7	0.8	8.2	2.7	3.7	65	90
June	0.1	1.5	3.8	5.8	0.9	2.3	52	63
July	0.2	0.2	4.6	2.6	1.0	0.8	52	57
August	0.8	0.2	2.0	2.9	1.1	0.9	33	80
September	1.5	3.1	1.6	3.5	1.5	3.2	20	46
October	6.5	4.6	6.1	3.5	6.4	4.3	42	54
Average	2.3	2.0	3.1	4.4	2.3	2.5	44	65

TABLE No. 62.—SUMMARY OF TOTAL NITROGEN APPLIED TO TANK No. 1, THE AMOUNT APPEARING IN THE EFFLUENT, THE AMOUNT STORED IN THE TANK, AND THE UN-ACCOUNTED FOR BALANCE, IN POUNDS.

	Dec., 1888.	Feb., 1889.	June, 1889.	Nov., 1889.	April 16, 1890.	June 18, 1890.	Nov. 24, 1890.	Mar. 25, 1891.	June 29, 1891.	Nov. 9, 1891.
Total nitrogen applied to date......	16.62	18.83	24.96	35.63	42.93	46.41	63.05	73.66	84.85	104.47
Amount in effluent to date...........	6.68	7.90	12.66	19.19	23.59	26.72	34.38	41.42	47.78	57.93
Amount stored in sand to date......	4.27	5.49	4.05	5.81	6.40	5.40	10.10	12.80	13.00	16.00
Amount lost to date.	5.67	5.44	8.25	10.63	12.94	14.29	18.57	19.44	24.07	30.54
Per cent. stored.....	26.	29.	16.	16.	15.	12.	16.	17.	15.	15.
Per cent. lost.......	34.	29.	33.	30.	30.	31.	29.	26.	28.	29.

cation, and the thing to be found out is chiefly the conditions most favorable to the action of the nitrifying organism. These are: (1) The presence of oxygen; (2) of moisture; (3) of an alkaline basic salt; and (4) of a temperature somewhat above freezing. In reference to temperature it may be said that nitrification is more active at from 60° to 70° F. than it is at materially lower temperatures, but once thoroughly started it will continue active for some time with temperatures only 5° to 10° above freezing.

In the later experiments at Lawrence it has been found that oxygen and time are the more essential elements in intermittent filtration, or, as expressed by Mr. Hazen: *

> The purification of sewage by intermittent filtration depends upon oxygen and time; all other conditions are secondary. Temperature has only a minor influence; the organisms necessary for purification are sure to establish themselves in a filter before it has been long in use. Imperfect purification for any considerable period can invariably be traced either to a lack of oxygen in the pores of the filter, or to the sewage passing so quickly through that there is not sufficient time for the oxidation processes to take place. Any treatment which keeps all particles of sewage distributed over the surface of sand particles, in contact with an excess of air for a sufficient time, is sure to give a well-oxidized effluent, and the power of any material to purify sewage depends almost entirely upon its ability to hold the sewage in contact with air. It must hold both sewage and air in sufficient amounts.

In Filter Tank No. 1, of the Lawrence experiments, the following are the elements: Total amount of sand, 9,000 gallons; amount of water contained when saturated, 3,240 gallons; when drained there remained 1,040 gallons of water, and in the place of the water drained away there had presumably entered into the voids the difference between the 3,240 gallons of water originally required to fill them, and the amount of 1,040 gallons which did not drain away, or 2,200 gallons of air.

This sand is so open that when all the water has drained away that will run from it, air can pass freely up through the five feet of sand

* 23d An. Rept. Mass. St. Bd. of Health, Filtration of Sewage, p. 428.

from the bottom to the top, and in addition the air in the sand is forced out through the underdrains by covering the surface with water. Fine sands, on the contrary, may be entirely saturated in the lower portion, while the upper layers are open and contain air. When therefore a filter composed of fine sand is covered with water on the surface, the free circulation of air through the voids is, under these conditions, cut off and the circumstances affecting nitrification and the life of organisms contained in the sewage passing through, materially changed. The effect of these changes may be recognized in two ways, (1) the coarse-sand filters may be made to purify a much larger quantity of sewage in a given time than those of fine sand; (2) the purification effected by the fine-sand filters on the smaller quantities purified by them under the conditions of ordinary operation will be somewhat superior to that effected by the coarse-sand filters, even when operating on quantities not much greater than the average for the fine sands. This phase of the subject will be further touched upon as we proceed.

Tank No. 2.

The foregoing discussion of intermittent filtration, so far as it relates to coarse-sand filters, is drawn from the data and tabulations in reference to Tank No. 1. In Tank No. 2 a clean fine sand of even grain was used, and the results with this tank indicate a somewhat higher degree of purification attained, though for smaller quantities of sewage applied per unit of area.

In the effluent the number of bacteria has been, after the beginning of nitrification, materially less than in the effluent of Tank No. 1. For a portion of the time they were less than 100 per cubic centimetre, and for a year averaged only 21. In five months of the year they averaged but 7.

The number of bacteria present in the sewage may be seen by reference to Table No. 59, including results of Tank No. 1.

Table No. 61 exhibits in compact form the results obtained with this tank after nitrification had fully begun.

Experiment with Trenches.

The soil of the field adjoining the experimental tanks at Lawrence is of fine river silt, somewhat finer than the sand used in Tank No. 2. In order to test the filtering qualities of such material *in situ* an area of about one-third of an acre was prepared by partially underdraining with drains 60 feet apart to catch samples of the effluent. These underdrains have been found of little use. Usually the liquid passes by them directly down to the water table, which is below them

a varying distance, depending upon the stage of water in the Merrimac river, which flows near by.

At the location selected the surface slope is about 1 foot in 10 in one direction and about 1 in 100 in the other.

A series of shallow trenches which follow the surface of the field, and are shown in plan and section by Fig. 23, were excavated in the original material in slopes, 1 foot in 30, 1 foot in 50, and 1 in 100. They were mostly made one foot wide, top and bottom, and of varying depths from six inches to three feet, and filled in with coarse mortar sand same as used in Tank No. 1. These trenches are made five feet apart and generally have the surface of the coarse filled-in sand four inches below the adjacent original surface, except at their lower end, where in 50 feet it increases to ten inches below. The length of each is about 200 feet, and except at the lower end the width is one foot, as stated.

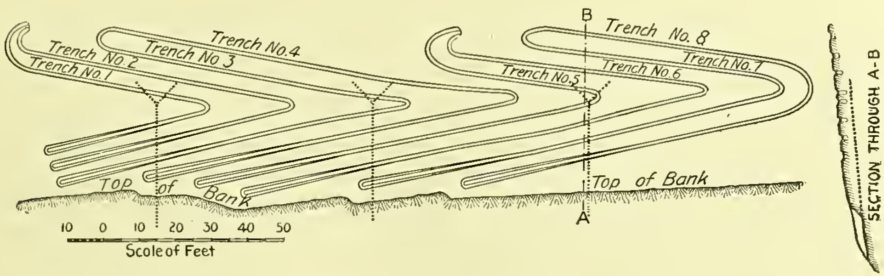


FIG. 23.—PLAN AND SECTION OF FILTER TRENCHES AT LAWRENCE.

The distance which sewage will flow along the surface depends upon: (1) The amount applied, and (2) upon the amount of sediment upon the surface; and this again varies with the quality of the sewage, the completeness of nitrification, and the time elapsed since the surface was cleaned. Sewage was applied to these trenches beginning in May, 1888, the quantity varying from 500 gallons a day for six days in the week, to 1,500 gallons daily, this latter quantity being applied to some of the trenches, 500 gallons at a time, at 9:30 A.M., 2 P.M., and 4:30 P.M.

After applying sewage in this way for from one to three months, the surface becomes so coated that a slight cleaning is desirable. This is effected by scraping off one-quarter of an inch in depth from the surface of the coarse sand filled into the trench.

In order to protect the trenches from frost, in the winter of 1888-9 they were covered with boards, and the process of purification having been found to proceed as readily under these conditions during the next spring as when exposed to air, the boards were allowed to remain.

The quantity of land through which the sewage applied to these trenches filters varies with the condition of the surface, and this again depends upon the frequency with which they are cleaned. During the fall of 1888 they were cleaned once a month, during the winter of 1889 once in two months, and in summer of 1889 once in four or five months, the board coverings having been added late in the fall of 1888. After a cleaning, the time before 500 gallons of applied sewage will reach the lower end varies from one to three months.

In material of the kind here used it appears probable that 50,000 to 60,000 gallons of sewage per day per acre may be efficiently purified with a renewal of the sand in the trenches not exceeding two inches annually. The expense of doing this will be considered further on.

Experiments with Fine Soil.

The experiments at Lawrence have also included an investigation of the filtering capacity of fine soil, and of areas of sand covered with soil. Filter Tank No. 5, in which the experiments on garden soil were conducted, had the bottom about the underdrains covered with coarse gravel, this again with finer gravel and coarse sand, making a depth of about seven inches, above which was a depth of five feet of fine garden soil.

From January, 1888, to October, 1889, inclusive, sewage was applied to this tank at varying average rates per month, from 19,200 gallons per acre per day in January, 1888, to 30,100 gallons per acre per day in April, 1888, after which the monthly average was gradually lessened to 3,800 gallons per acre per day in February, 1889, then rising to an average of 8,400 gallons in August, 1889.

During April, 1888, when sewage was applied at the rate of 30,000 gallons per acre per day, this amount disappeared from the surface within six hours after its application; but in the latter part of May, it did not always disappear in 24 hours. In June the quantity was reduced to 20,000 gallons per acre per day, and still accumulated on the surface. For a week, in July, no sewage was applied, and some of the accumulation remained upon the surface five days.

The result of the experiments with Filter Tank No. 5, shows that garden soil is entirely unadapted to the purification of sewage by filtration, even in small quantities. During the six months, from May to October, 1889, sewage was applied at the rate of only 7,500 gallons per acre per day. During this time there was no nitrification, and the albuminoid ammonia of the effluent was 82 per cent. of that of the sewage.

Experiments with Sand Covered with Soil.

In Filter Tank No. 7, the lower four feet was composed of the usual seven inches of gravel and sand, around and above the underdrains, with a mixture above of fine gravel and coarse and fine sand. Above this four feet of gravel and sand there is in addition six inches of brown soil.

In May, 1888, sewage was applied at the rate of 30,000 gallons per acre per day, except on six days when none was applied. In the early part of June this quantity did not all disappear in twenty-four hours; after June 14 the quantity was reduced to an average of 13,800 gallons per acre per day to the end of the month. During this time 9,000 gallons per day came through, the remainder evaporating and accumulating on the surface. From July 1 to 11 an average of 9,000 gallons a day was applied; at the same time the effluent averaged 4,400 gallons. After July 11, the application was discontinued until July 25. During this time the sewage remained upon the surface for 12 days, finally disappearing July 24th.

On July 25, ½ inch in depth of the surface was removed, and sewage applied at the rate of 20,000 gallons per acre per day. With a fresh surface this quantity disappeared in 53 minutes. The same amount was applied daily for six weeks. In ten days it required an hour and a half to entirely disappear from the surface. After August 16 the sewage disappeared much more slowly, and some days not at all. After September 8, the quantity was reduced to an average of about 13,000 gallons per acre per day, or exactly 90,000 gallons per week, applied three times a week, 30,000 gallons at a time. In October sewage gradually accumulated on the surface, and the application was in consequence reduced in November to a total of 60,000 gallons per acre per week, applied 20,000 gallons at a time, on three days in the week. During this time the effluent amounted to 10,800 gallons per acre per day.

The experiments on Tanks Nos. 5 and 7 indicate a marked decrease in the nitrification as soon as the sewage accumulates to any considerable extent on the surface. When allowed to accumulate upon the surface long enough to completely exclude air from the interstices of the filter, the nitrification either nearly, or completely ceased. Discontinuing the application of sewage, until the surface cleared itself was followed in every case by an increase in nitrification.

The experiments on these two tanks have therefore illustrated one of the chief differences between continuous and intermittent filtration.

The following is the summary of advantages and disadvantages of soil on the filter area, as given by Mr. Mills :

The experiments have been limited to fine soils, quite retentive of water.

With a depth of 5 feet of soil no purification by nitrification occurred when the quantity filtered was only 7,500 gallons per acre per day ; and the organic nitrogenous matter in the effluent was nearly as great as in the applied sewage. It is known, however, that for several months the average number of bacteria in the effluent was only one in 25,000 of the number applied to the filter ; and it is probable that none lived to pass through the filter.

With the ordinary depth of soil resting on yellow loam, as it is often in this State, and this underlaid by four feet of good filtering sand, we find that only about 9,000 gallons of sewage may be filtered upon an acre daily, with the result of removing 99.5 per cent. of the organic matter, and probably removing all of the bacteria ; while if the soil and loam be removed, the underlying sand may be able to filter three times as much, or 30,000 gallons per acre per day, giving an effluent as pure, chemically, as when covered with soil, but not removing so completely the bacteria—allowing, ordinarily, a small fraction of one per cent. to pass through the filter.

For filtering sewage upon the margin of a drinking-water stream, a large area covered with fine soil, or a smaller area of very fine sand, would be preferable to a much smaller area of coarse sand or a mixed sand and gravel, in that the former could be so managed that no bacteria could pass through. For filtering sewage on any land that does not drain into a drinking-water stream, the covering of fine soil is a disadvantage. The quantity applied to it must be kept very small, or nitrification and purification will be prevented. The smaller areas of sand can be made to give as good an effluent, chemically, with all the reduction in the number of bacteria that is necessary.

Experiments with Peat, Loam, etc.

In addition to the experiments upon the filtering capacity of fine retentive soils, an extended series were also made upon peat and loam, and peat mixed with sand, clay, etc., in various proportions. The tanks devoted to these experiments with peat were Nos. 3, 15, 16, 17, and 18.

Tank No. 3 was one of the large tanks with an area of one two-hundredth of an acre. The underdrains were laid in the usual depth of 7 inches of gravel and coarse sand, above which was five feet of peat, consisting of nearly all vegetable matter, except that it contained a little mud. The top of the original bed, from which this peat was derived, had been cultivated. The cultivated top layer was removed and the tank filled with selected material to the depth of four feet from the undisturbed lower layers ; after which one foot in depth of the cultivated upper layer was added to the peat.

Without going into the detail of the experiments with this peaty material, it is sufficient to say, the results indicate that such an area is " entirely worthless for the filtration of sewage."

Tanks Nos. 15, 16, 17 and 18 were small tanks, placed within the building, and each having an area of one twenty-thousandth of an acre. Coarse gravel and coarse sand to the depth of about six inches were

placed in the bottom of each tank, and served as underdrains to the filtering material.

In Tank No. 15, the filtering material consisted of 2½ feet of peat overlying peaty sand and sand.

In Tank No. 16, the lower 3½ feet of filtering material was peaty sand, and clear sand, with a depth of 1½ feet of peat above.

Tank No. 17 contained 3½ feet of peat, underlaid with peaty sand and sand.

Tank No. 18 contained five feet in depth of peat, mixed with some very fine sand and some clay.

In regard to the results of experiments with Tanks Nos. 15, 16, 17, 18, filled with peaty materials, Mr. Mills says: "These materials were all found to be quite worthless for the filtration of sewage."

Experiments on mixed sand and gravel further indicate the utility of an open material.

Experiments with Coarse Gravel.

Probably as interesting and useful experiments as any are those on filtration through clean gravel. In this direction, two series have been made: (1) Those on very coarse, clean gravel; and (2) those upon fine clean gravel. We will briefly refer to the second series, where the filtering material was composed exclusively of five feet in depth of gravel stones of the size of beans. The sand was screened out and the stones washed clean before putting into the tank. The voids were

Table No. 63.—Daily Quantity of Effluent in Gallons per Acre; the Average Amounts of Ammonia, Nitrates, and Bacteria in the Effluent; and the time of Passing Through one foot for the Month Indicated. Tank No. 2, Clean Fine Sand.

(Parts per 100,000.)

Date.	Daily quantity of effluent, gallons per acre.	Ammonia.		Nitrates.	Per cent. of nitrogen applied coming off as nitrates. (Corrected for quantity.)	Number of bacteria per cubic centimetre.	Time of passing through one foot of saturated layer, days.
		Free.	Albuminoid.				
1888.							
November	13,800	0.0003	0.0072	0.863	39	11	11.0
December	11,800	0.0005	0.0064	0.784	29	5	13.0
1889.							
January	12,600	0.0008	0.0060	0.762	48	12	10.7
February	11,400	0.0008	0.0059	0.736	55	23	13.0
March	25,800	0.0009	0.0077	0.661	41	28	6.0
April	39,600	0.0201	0.0095	1.713	73	7	4.0
May	27,400	0.0019	0.0098	2.256	96	57	5.5
June	22,600	0.0020	0.0104	1.638	73	38	6.6
July	27,000	0.0020	0.0094	1.000	28	57	5.7
August	24,000	0.0008	0.0074	0.504	21	6	6.0
September	33,400	0.0013	0.0078	0.864	32	8	4.5
October	37,800	0.0044	0.0090	1.376	47	7	4.0

TABLE No. 64.—AVERAGE QUALITY OF THE EFFLUENT FROM A FINE-GRAVEL FILTER IN COMPARISON WITH THE ORIGINAL SEWAGE WHEN FILTERING AT THE RATE OF 108,500 GALLONS PER ACRE PER DAY (SEWAGE APPLIED 14 TIMES A DAY FOR SIX DAYS IN THE WEEK).

(Parts per 100,000.)

1889.		Ammonia.			Chlorine.	Nitrogen as		Bacteria per cubic centimetre.
		Free.	Albuminoid.	Sum of.		Nitrates.	Nitrites.	
Sept. 24—Oct. 24....	Sewage...	2.0559	0.6453	2.7012	5.55	0.0	0.0	3,034,000
	Effluent..	0.0068	0.0325	0.0393	6.42	1.5700	0.0003	11,592
	Per cent.	0.3 of 1	5.	1.5	....	......	......	0.4 of 1

fully one-third of the total space, as in the sand filters already described. Tables Nos. 64 and 65 exhibit the results obtained by such a material, the tanks being protected from snow and exposure to cold during winter weather.

In concluding the discussion of the results of the Lawrence experiments we can hardly do better than to quote the remarks of the Massachusetts Board in the Twenty-second Annual Report in reference to the results of intermittent filtration through gravel stones, namely:

These results show more definitely than any others the essential character of intermittent filtration. We see that it is not a straining process. By the application of small quantities of sewage over the whole surface of the tank each hour, each stone in the tank was kept covered with a thin film of liquid, very slowly moving from stone to stone from the top toward the bottom, and continually in contact with air in the spaces between the stones. The liquid, starting at the top as sewage, reached the bottom within twenty-four hours, with the organic matter nearly all burned out. The removal of this organic matter is in no sense a mechanical one of holding back material between the stones, for they are as clean as they were a year ago; but it is a chemical change, aided by bacteria, by which the organic substances are burned, forming products of mineral matter, which pass off daily in the purified liquid.

TABLE No. 65.—AVERAGE QUALITY OF THE EFFLUENT FROM A FINE-GRAVEL FILTER IN COMPARISON WITH THE ORIGINAL SEWAGE, AFTER FILTRATION HAD TAKEN PLACE AT RATE OF 70,000 GALLONS PER ACRE PER DAY FOR SEVEN MONTHS, ETC. (SEWAGE APPLIED 9 TIMES A DAY FOR SIX DAYS IN THE WEEK).

(Parts per 100,000.)

1889.		Ammonia.			Chlorine.	Nitrogen as		Bacteria per cubic centimetre.
		Free.	Albuminoid.	Sum of.		Nitrates.	Nitrites.	
May 23—June 22....	Sewage..	1.9919	0.6031	2.5950	5.16	0.0	0.0	......
	Effluent.	0.0031	0.0375	0.0406	6.00	2.0700	0.0002	10,305
	Per cent.	0.2 of 1	6.	1.5	......	......	......	......
June 23—July 22....	Sewage..	2.2500	0.7255	2.9755	7.46	0.0	0.0	1,813,500
	Effluent.	0.0050	0.0354	0.0404	9.01	2.2500	0.0004	13,523
	Per cent.	0.2 of 1	5.	1.3	......	......	......	0.7 of 1

The liquid flowing out at the bottom is a clear, bright water, comparing favorably, in every respect that can be shown by chemical or biological examination, with water from some of the wells on the streets of our cities that are used for refreshing draughts by the public during the summer.

On the Use of the Effluents for Drinking Water.

In regard to the use of the effluent from sand filters for drinking, Mr. Mills writes as follows:

We now come to the important question of the character, as regards healthfulness, of the effluents obtained by filtering sewage intermittently through five feet in depth of sand, after the sand has filtered sewage for a year or more without being cleaned.

We have found that the sum of ammonias, which have been taken to indicate the amount of nitrogenous organic matter, has been reduced to about one-half of one per cent. of those in the sewage, and is less than the sum of ammonias of most of the public drinking-water supplies of the State.

The chlorine and nitrates are higher than in the public drinking waters. They indicate in these effluents, as their excess above the normal does in the drinking waters, that the water which contains them came from sewage; but, in the absence of the ammonias, they indicate that, though the water came from sewage, the organic impurities have been destroyed, and these are merely mineral constituents which remain after that destruction. They are principally common salt and saltpetre, which, in the quantities found in any of the effluents, are regarded as entirely harmless.

Judging by the chemical analyses, there is nothing in the effluents known, or even suspected by chemists, to be harmful.

Although nearly all of the bacteria that were in the sewage did not live to pass through the filters, there have been found in the effluents from filters of coarse sand more bacteria than are found in the public drinking supplies, and some of these evidently come from the sewage; and, until we learn that disease-producing bacteria are not among those that come through, we must assume that they may be among them; and, although reduced in numbers to such an extent that they may do no harm, we yet know that bacteria in general increase with enormous rapidity when under favorable conditions, and we do not yet know enough to allow us to assume that the very small number of one or two in a thousand of the number in the sewage that come through may not increase in the human body or under other conditions to such numbers as to be harmful.

From this cause we are not able to assume that the effluent from the coarse-sand filters five feet in depth is suitable for drinking water.

The effluent from the extremely fine sand filter, No. 4, and that from the soil-covered filter, No. 7, and a part of the time from the fine sand, No. 2, we have strong ground for concluding contained no bacteria from the sewage. The numbers that were found in the effluents were smaller than are usually found in public drinking supplies; and we have good reason for concluding that they all grew in the gravel and underdrains beneath the filters. If these conclusions are correct, there is no known reason why these effluents may not be used with safety for drinking.

The effluent from No. 2 has been frequently used for drinking by a number of people, without any noticeable effect; but none of them have been used continuously by a large number sufficiently to prove their safety. In the absence of such positive evidence, we have made the following comparisons.

The city of Lawrence is provided with a public water supply from the river; but there are a dozen or more wells scattered about the city, on the sides of the streets, that have been used for many years for watering horses, and are still used for this purpose, or for supplying drinking water to families in the neighborhood, and particularly are used by the public for a cool draught of water in summer, when it is much more refreshing than the city reservoir water.

The water from ten of these wells has been analyzed and examined for bacteria, and the results obtained from seven of them are arranged below (Table No. 66), with the average result obtained by analysis of the filtered sewage from six of our filters, covering from two to eight months, after most of them had been in use a year or more.

TABLE No. 66.—COMPARISON OF THE EFFLUENT FROM SEVERAL OF THE EXPERIMENTAL FILTERS WITH WATER FROM WELLS IN THE CITY OF LAWRENCE IN COMMON USE.

(Parts per 100,000.)

Average effluent from	Ammonias.			Chlorine.	Nitrogen as		Bacteria per cubic centimetre.
	Free.	Albuminoid.	Sum.		Nitrates.	Nitrites.	
Tank No. 1, for two months	0.0313	0.0272	0.0585	4.83	1.78	0.0008	549
Well water, Atlantic street	.1410	.0155	.1565	8.08	2.37	.0024	4,370
Tank No. 13, for six months	.0011	.0105	.0116	7.28	1.25	.0004	76
Well water, Hampshire street	.0078	.0118	.0196	7.51	2 00	.0007	128
Tank No. 6, for 3 months	.0036	.0104	.0140	4.98	1.66	.0002	678
Well water, Andover street	.0184	.0046	.0230	2.79	1.50	.0018	46
Tank No. 6, for six months	.0014	.0074	.0088	4.51	1.11	.0001	319
Well water, Mechanic street	.0016	.0076	.0092	5.29	4.20	.....	240
Tank No. 4, for two months	.0025	.0108	.0133	3.72	0.75	.0002	20
Well water, Salem street	.0070	.0086	.0156	7.67	1.40	.0014	447
Tank No. 2, for four months	.0007	.0065	.0072	3.98	0.75	.....	17
Well water, Lowell street	.0012	.0070	.0082	7.11	2.10	.....	27
Tank No. 7, for eight months	.0014	.0063	.0077	4.04	1.06	.....	7
Well water, Haverhill street	.0022	.0050	.0072	2.44	0.55	.0016	344

Here we find, for each of the filters filtering sewage, a well the water of which is used for drinking by many people, but is in fact sewage not so well purified as the effluent from the filter with which it is associated. This is not presented to show that the effluent from the filters is good for drinking, for we have no reason to so regard those at least in the upper half of the table, and we should without hesitation pronounce the well waters in the upper half of the table as unsafe to drink; but we present this comparison to show that waters in every way as impure, and as certainly derived from sewage as the effluents from the several sewage filters, are being used daily, and have been used for years by multitudes of people, without their knowing that they were harmed by them.

Every one of these wells should be regarded as unsafe, some of them dangerous, in their present condition, and others unsafe because of what they may change to from day to day.

If these wells contained unpolluted water, the chlorine would be about 0.36, while it is from seven to twenty-two times this amount; the nitrates would be about 0.01 or 0.02, while they are from 0.55 to 4.20.

The latter show that a large amount of organic matter, generally more than there is in sewage in a sewer, has been burned out of these waters, and the high chlorines show that this organic matter was of the same character as that in sewage. From the amounts in most of these well waters we must conclude that their previous condition was worse—that is, more polluted—than ordinary sewage in sewers, and that on its way to some of the wells it has by intermittent filtration through the ground been purified to such an extent that they may not in their present condition be harmful; and, where the numbers of bacteria are continually small and the ammonias low, they probably are not harmful; but, where the numbers of

bacteria are large and the ammonias are large, although the waters have been previously much worse than at present, and have to a considerable degree been purified, their present condition indicates that the material through which they have filtered has not been able to exclude bacteria nor to burn up all of the food they live on; hence, if disease germs get into their source, some of them will probably get into these wells. Such of the wells as are included in this latter class should be filled with earth, and never used again. Others, if examined from time to time and always found with low ammonias and small number of bacteria, would probably be harmless; and we should have the same ground for concluding that the effluent from sewage at those fine sand or soil-covered filters, through which no bacteria come from the sewage, would also be harmless for drinking.

Permanency of Filters and Renewal of Sand.

In the Twenty-third Annual Report of the Massachusetts State Board of Health, pp. 449–55, the permanency of sand filters is discussed, and the fact brought out that while some of the experimental tanks at Lawrence were doing good work after four years of continuous service, yet others had stored so much organic matter as to "seriously cripple" them. The report then discusses, as two methods of obviating this difficulty, either turning under or removing the clogged layers. Turning under the upper portion of the filtering material has given good results in the way of reducing the stored organic matter, but it is suggested that while receiving fresh doses of sewage the bacteria will not do their best work upon the insoluble matter, as the stored substances have been found to be, largely. Mr. Hazen's discussion of this point, and the amount of sand necessary to be renewed, is as follows:

> The fact of continually increasing storage in the large out-door filters is sufficient evidence that they do not afford conditions favorable to the oxidation of this material. On them we have applied as much sewage as was possible with good results, and much more than is usually applied in practice. In a majority of cases—always with the fine materials, and often with the coarser ones—this has meant as much sewage as could be oxidized by the air in the filter. All the air available has been required to oxidize the more decomposable matters; the more stable insoluble matter, we may believe, can only receive the attention of the bacteria when there is an excess of air. Filters do their maximum work when the volume of sewage applied is so large that there is no considerable excess of air, when the supply exactly meets the present demand, oxidizing only the less stable matters and preventing their passage into the effluent. There may also be a question as to whether the bacteria will do their best work upon this insoluble matter while they are receiving a daily dose of fresh sewage, with its rich supply of food for them.
>
> If the fresh sewage were entirely cut off, would not the bacteria turn their attention to the sludge? If the upper layer were removed entirely and piled up by itself, would it not purify itself much more rapidly than anywhere in a filter where it is continually wet with new sewage? If this clogged material is removed, the filters will be able to continue doing the large amount of good work which they have done in the past; they may do even more in some cases. The removed material may so purify itself in time as to again allow its advantageous use for filtration, but, if not, fresh sand must eventually be supplied. In actual practice with ample areas of filtering material a simple way of applying these ideas would be to abandon for a time an old area, after it had become clogged, without removal of the surface.

How long a time would be required for such an area to regain its power of sewage purification, and what treatments would hasten the result, are subjects for further research.

NATURE OF THE SLUDGE.

It may be queried whether piling up sand containing large amounts of organic matter stored from the sewage will not create a nuisance. To this we can answer no. The stored matters are the most stable portions of the sewage; they have resisted strong oxidizing action, and are incapable of rapid or objectionable decomposition. The matters which would have caused trouble had they been stored are just the ones which have been oxidized. The material should be so placed that a change of air in its pores will be possible, and no offence need be anticipated.

AMOUNT OF SAND NECESSARY TO BE RENEWED.

Filter No. 6 in four years' use has filtered 310,000 gallons of sewage, the equivalent of 62,000,000 gallons per acre. The upper 2½ inches of material now contain about 70 parts per 100,000 by weight of albuminoid ammonia, and the next 3 inches about 20 parts. To fully restore the filter to good working order we should remove the upper 2½ inches, or 1.68 cubic yards for the filter, or 5.4 yards per million gallons of sewage treated. In July, 1891, when Filter No. 1 commenced to be seriously clogged, the layer with excessive organic matters was not more than 3 inches deep, although more than 400,000 gallons of sewage (800,000,000 gallons per acre) had passed. In this case the removal of two yards, or at the rate of 5 yards per million gallons of sewage treated would have sufficed. In June, 1891, the surface of Filter No. 2 was clogged not more than two inches deep after filtering 230,000 gallons (46,000,000 gallons per acre), corresponding to 5.8 yards per million gallons. The sand below this upper layer contains some stored matter, which would be carried forward to the next account, and might eventually raise the amount of sand to be removed to eight or even ten yards per million gallons. On the other hand, so far as this sand regains its power of purifying sewage this amount will be reduced. If the sewage contained more or less suspended matter, correspondingly more or less new sand would be required, and if the suspended matter was first removed from the sewage by settling, we may believe that the amount of sand to be removed would be very small. Experiments are now in progress to determine this point.

The Effect of Frost and Snow Upon Intermittent Filtration at Lawrence.

As has already been intimated in this chapter, frost checks nitrification, but its bad effects may be guarded against so effectually as to make it no serious obstacle in the way of intermittent filtration. Aside from the winter application of sewage to covered trenches, at the Lawrence Experiment Station other experiments have been made to determine the effect of frost upon filter beds. The results of these experiments are outlined by Mr. Hazen in the Twenty-third Annual Report of the Massachusetts State Board of Health, pp. 441–7, from which the following is taken:

During the first winter, 1887–88, the various filters were exposed to the weather without protection, and no nitrification was obtained until the temperature began to rise in the spring. The result might have been different if the filters had been nitrifying well before cold weather. During the two following winters the filters

were protected from snow, and to a certain extent from cold, by canvas covers. It was found that when the filters were so protected, almost, if not quite, as good results were obtained in the winter as during the warmer months, and it was established, as stated in the special report upon Purification of Sewage and Water (pages 29 and 255), that intermittent filtration is entirely practicable in this climate, if snow is kept from the filtering area.

We had no satisfactory information, however, as to what results could be obtained from unprotected filters. Accordingly, in the winter of 1890–91 the outdoor filters were left exposed to the weather. Filters 1, 2, 4, and 6 were receiving from 34,000 to 103,000 gallons of sewage per acre daily, and were free from complications, so that they furnish the best data in regard to frost. . . .

CARE OF THE FILTERS IN WINTER.

When sand is frozen solidly after draining there still remain open pores through which the sewage easily finds its way, thawing to some extent the frost as it proceeds. After the sewage has drained away, the portion which remains in the sand again freezes, but open pores are still left which allow the passage of the next portion of sewage. If, however, the sewage settles away very slowly, it will freeze before the sand drains, and in this case no pores are left, and the next application of sewage will remain upon the surface and freeze solidly, if the weather is cold enough. If snow is upon the surface of the sand and sewage is applied uniformly to it, it is at once chilled to the freezing point, and has then no power of thawing the frost in the upper layers of sand; and if the weather is cold the whole will solidify on the surface, effectually closing the filter. The two essential conditions to the passage of sewage through the filters in winter are that sewage shall never be put into snow, and that the filtering material shall be open enough to absorb its dose rapidly.*

Sewage was applied uniformly at a temperature of from 44° to 46°, or the average sewer temperature in winter. . . . All snow was promptly removed from the filters by shovels. Each week the surface was disturbed. If the sand became sufficiently thawed at any time when it was not sewage covered, it was then raked. When there was no such opportunity for raking, the surface was disturbed with a pick in numerous places. During December no record was kept of the exact time required for this work on the several filters; it was about the same as for January. For January, February, and March it was as follows, in hours' work for one man on one two-hundredth of an acre:

Filter.	January.	February.	March.	Total.†
No. 1	9	3	3	15
2	7	3	3	13
4	4	1½	1¼	6¾
6	4½	3½	2½	10½

† This column has been added by the authors. These results cannot be taken as in any degree indicating what will be obtained in actual practice, where, if it became necessary to remove snow and stir up the sand from day to day, as was done in the experiments, it could be accomplished at far less expense by the use of mechanical appliances. Apparently, a somewhat more rational treatment of this problem is indicated in Chapter XVII. Certainly the use of from 1,500 to 3,000 days' labor per winter for hand removal, as indicated by Mr. Hazen's statistics, or any amount of labor approximating thereto, would be impracticable. Though it should not be overlooked, in considering Mr. Hazen's results, that while they indicate nothing as to cost of removing snow in actual practice, they do still indicate the extent of winter purification under the special conditions.

. . . .

RESULTS.

As soon as frost began to form freely in the various filters a marked change was noticed in the chemical composition of the effluents; the free ammonia in-

* It should be said that with the conditions which obtain in actual practice with regard to the method of applying sewage, no serious difficulty has been experienced in Massachusetts in disposing of sewage in winter on porous ground.

creased, and soon the nitrates decreased. The organic matters, as shown by the albuminoid ammonia and by the oxygen consumed from permanganate, also increased, but not to an extent corresponding with the fee ammonia. During the colder months nitrification was much checked; ammonia, instead of nitrates, was largely the end product of the oxidation, so far as nitrogen was concerned. The first stage of purification, namely, the oxidation to ammonia and carbonic acid, was not affected to the same extent.

A table introduced at this point (p. 443 of the report) shows the average albuminoid ammonia in the applied sewage and the effluents from the four experimental filters. These same figures, put in the form of percentages of organic matter remaining in the effluent after filtration, are quoted from the report as follows, the tanks being arranged in order of fineness of material, No. 1 being very coarse sand, No. 6 coarse, No. 2 of fine, No. 4 very fine sand:

Table 66A. — Percentages of Organic Matter in Effluents from Experimental Filters in Winter.

	Average temperature of effluents. Deg. Fahr.	Per cent. of organic matter remaining in.			
		No. 1.	No. 6.	No. 2.	No. 4.
October, 1890	58	3.5	2.6	1.3	1.9
November, "	47	4.6	2.1	1.0	1.2
December, "	40	15.5	2.9	1.7	1.7
January, 1891	37	20.0	8.9	4.8	3.0
February, "	36.5	11.0	12.0	5.0	5.0
March, "	38	5.0	5.4	4.4	4.3
April, "	45	4.7	4.4	3.2	4.7
May, "	54	3.7	2.9	2.7	1.7

Quoting again from the report:

During the colder months of the year there was a period with each filter of about three months, during which purification was much less complete than at higher temperatures. The time of this period varied in the different cases: the coarse materials were the first to suffer; the finer sands were not so soon affected, but the period was as long, extending into warmer weather. With No. 1 a marked improvement occurred while the temperature of the effluent was still decreasing. With Nos. 2 and 6 the highest organic matter was coincident with the lowest temperature, while No. 4 followed some weeks later. During December the frost was particularly troublesome in Filter No. 1, and the distribution of sewage was imperfect, most of it going down through limited unfrozen areas. Later the frost was broken with picks, and better distribution was obtained. This explains probably, in a large measure, why the worst results were obtained so early in the season. It is also possible that the filter became in some way adapted to the frost; that, after a few weeks of use, the portions of the filter below the frost did their work more thoroughly than at first, regardless of temperature, for the same reason that any filter gives its best result after it has been used for a time.

The average numbers of bacteria per cubic centimetre by months were as follows:

TABLE No. 66 B.—BACTERIA IN EFFLUENTS FROM EXPERIMENTAL FILTERS IN WINTER.

Month.	Temperature, degrees, Fahr.	Sewage bacteria.	Filter No. 1.		Filter No. 6.		Filter No. 2.		Filter No 4.	
			Bacteria.	Per cent.	Bacteria.	Per cent.	Bacteria.	Per cent.	Bacteria.	Per cent.
October, 1890	58	2,487,000	16,000	.64	13,000	.52	17	.0007	39	.0016
November, "	47	1,157,700	24,000	2.07	9,000	.78	36	.0031	45	.0040
December, "	40	874,400	58,000	6.60	8,400	.96	284	.0280	35	.0040
January, 1891	37	456,000	51,000	11.20	27,000	5.90	822	.1800	19	.0042
February, "	36.5	301,000	9,000	3.00	20,000	6.70	78	.0260	179	.0596
March, "	38	563,000	4,400	.78	6,000	1.10	37	.0066	15	.0026
April, "	45	375,000	2,900	.77	4 500	1.20	50	.0130	28	.0074
May, "	54	1,370,000	11,000	.80	4,700	.34	44	.0032	6	.0004

. . . .

The albuminoid ammonia and bacteria in the effluents, in percentages of those of the sewage for the worst month, worst three months, and for a period in warm weather as nearly as possible comparable, are as follows :

	Filter No. 1.		Filter No. 6.		Filter No. 2.		Filter No. 4.	
	Albuminoid ammonia.	Bacteria.	Albuminoid ammonia.	Bacteria.	Albuminoid ammonia.	Bacteria.	Albuminoid ammonia.	Bacteria.
Worst month	20.0	11.20	12.0	6.70	5.0	.18	5.0	.059
Worst three months	15.5	7.30	8.8	4.60	4.7	.078	4.7	.022
Warm weather	5.0	1.20	2.6	.77	1.6	.003	1.5	.008
Ratio, warm weather to worst three months	3.1	6.	3.3	6.	2.9	26.	3.1	3.

With the sub-surface application of sewage on Filter No. 7, which has a distributing pipe eighteen inches below the surface, no bad effects from the cold weather have been observed. The effluent during the months, January to July, 1891, was not of as good a quality as at other times, but it is believed that this was due entirely to over-dosing, and not to the temperature. This view is confirmed by the results during the succeeding winter, when, with a smaller dose, uniformly good purification was obtained, and the fluctation in the free ammonia bore no relation to the weather.

To resume : We have found that frost checks both purification and nitrification, although the removal of the organic matter is more complete than the oxidation of ammonia. The principal disturbance from cold weather did not last more than three months, although nitrification was more or less incomplete for a longer period. During those three months the effluents from the different filters contained, in each case, about three times as large a proportion of the organic matters of the applied sewage as the effluents from the same filters contained under comparable conditions in warmer months.

During the winter months the filters removed :

	Albuminoid ammonia. Per cent.	Bacteria. Per cent.
Filter No. 1, very coarse sand	84	93
" 6, coarse sand	92	95
" 2, fine sand	95	99.92
" 4, very fine sand	95	99.98

These results are good, although less perfect than those obtained in the warmer months. With the fine materials the purification is most complete, but even with the coarsest, No. 1, the result is far better than could be obtained by any process of chemical precipitation.

Frost and Snow at the Filter Beds at South Framingham, Massachusetts.

It has been found in actual practice at South Framingham, Mass., that snow serves as a protection to the filter beds, allowing the sewage

Fig. 24.—Snow-covered Sewage Filter Bed at South Framingham, Mass.

to spread over the beds, beneath it, without freezing. The following account of the application of sewage to frozen and snow-covered beds is of special interest in this connection, as is also the accompanying view, Fig. 24.

During the cold weather of January, 1893, some observations of the effect of frost on filter beds were made by the Sewer Commissioners of South Framingham, Massachusetts, at the suggestion of Mr. Allen Hazen. The results were published in the Framingham *Gazette*, from which the following has been abstracted:

A filter bed with an area of seven-eighths of an acre received no sewage from some time in September until Jan. 9. On this date there were 18 inches of frost in the bed and 10 inches of snow upon it, the

thermometer reaching 6° F. below zero. Jan. 9, 300,000 gallons of sewage were applied to the bed, and on Jan. 10, 150,000 gallons. It is said that the effluent appeared in the underdrain in six hours after the application of the sewage. On Jan. 11 the frost was, in places, out of the bed for its whole depth, and on Jan. 12 it was nearly all gone and the sewage had disappeared from the surface. The temperature of the applied sewage was 50° F.

On Jan. 16, 17 and 18 observations were made on another bed, with an area of one acre. The frost in this bed was from 20 to 30 inches deep, and there were 15 inches of snow upon it. On Jan. 16 the thermometer indicated 6°, on Jan. 17, 20°; and on Jan. 18, 4° F. below zero. On Jan. 16, 500,000 gallons of sewage, at a temperature of 49° F., were pumped upon this bed, and on Jan. 17, 175,000 gallons. The underdrain started in seven hours after beginning the application of sewage. On Jan. 18, the frost was out of the ground in places, and on Jan. 19 nearly all out, while the sewage had entirely disappeared from the surface.

. . . .

At the South Framingham pumping station an underground reservoir provides storage for about 430,000 gallons of sewage, which, with the sewage delivered during pumping, would allow the application of 500,000 gallons of sewage to one bed in about six hours. This amount of sewage was applied to one of the beds, with an area of one acre, in one day, and 175,000 gallons additional on the following day. The application of so large a volume of sewage at a temperature of about 50° F. in so short a time was certainly favorable to the passage of the sewage, but the presence of 15 inches of snow was decidedly unfavorable.*

A view of one of the South Framingham beds covered with snow is shown by Fig. 23. The bed has an area of about seven-eighths of an acre. It received no sewage from the middle of October, 1892, until Feb. 12, 1893. On the latter date there was from 30 to 36 inches of frost in the ground and 30 inches of snow on top of it. From Feb. 12, to March 1, when the view was taken, about 50,000 gallons of sewage per day was applied to the bed, going beneath the snow, as can be seen in the view.

Snow on the Filter Beds at Summit, New Jersey.

In the winter of 1893 an unusual amount of snow fell at Summit, New Jersey, which is a short distance from New York City. The ground having been covered with snow for many weeks, the writer visited the Summit filter beds on March 6. Most of the beds were entirely cov-

* Eng. News, vol. xxix., p. 174 (Feb. 23, 1893).

ered with snow and ice, and all partially so. Sewage was being applied to several beds and finding its way beneath the snow. The attendants stated that the snow had not stopped the filtration, although it had required unusual care to prevent some of the beds from filling and overflowing.*

The special subject of winter management of filter areas is treated at length in Chapter XVII.

Summary.

We may now pass to the summary.†

(1) Intermittent filtration through coarse sand is not a process of straining at all, but is, on the contrary, a biological process in which the nitrifying organism, with the assistance of oxygen from the air and the minerals naturally in solution in sewage, resolves the organic matter of sewage into soluble mineral nitrates and probably free nitrogen gas, the whole process, when properly conducted, taking place essentially without the production of odor.

(2) The conditions for successful treatment are: (*a*) Intermittency of application, and (*b*) open spaces between the particles of the filter (the voids) to which air easily gains access.

(3) In sand filtration areas the relations of the spaces occupied by sand, liquid, and air will vary for different qualities of material, with the result of producing variations in the quality of the effluents. The experiments, however, enable one to decide approximately: (*a*) What degree of purification may be obtained with a given material; and (*b*) the unit quantity of sewage that may be purified within limits to any required standard with a given material. We may therefore say that sewage purification by this process now has not only a scientific basis, but, in general terms, is amenable to computation in reference to what may be accomplished by it under given conditions.

(4) As a detail of practical management, Mr. Mills says that while with a filter of coarse open sand some bacteria may pass through the filter, nevertheless with the underdrains as deep as practicable and as far apart as will serve to drain the quantity of sewage to be applied, if the sewage be applied in small quantities at a time, rather than in large quantities, and more frequently than with large quantities, the number of bacteria passing through will be less than if the whole daily application is made at one time.

These deductions are based on the Special Report, covering the

* Further details regarding this visit can be found in Eng. News, vol. xxix. (Mar. 16, 1893), p. 248.

† The intention here, as in the previous case of the Massachusetts experiments on chemical purification, is, whatever the form of language used, to assume the responsiblity of the views expressed in the summary. This is only just when an attempt is made to condense several hundred pages into three or four.

years 1888 and 1889. In 1890 and 1891 Tank No. 1, in use since 1888, filtered sewage at the rate of 85,920 gallons per acre daily for every day of the time, removing 94% of the organic matter, as determined by the albuminoid ammonia, and 98% of the bacteria.

(5) The general result with clean, sharp, coarse sand filters, as determined by experimenting with four such filters, is: (*a*) That 60,000 gallons per acre per day may be filtered, with the result of removing from 97 to 99 per cent. of the organic matter, and giving an effluent always colorless, generally clear, and with very little or no sediment; (*b*) larger quantities up to 180,000 gallons a day may be filtered, and 97 per cent. of the organic matter removed for several months at a time; and (*c*) when filtering 60,000 gallons a day, such a filter will remove an average of 99.9% of the bacteria in the sewage.

(6) As a deduction from (4) and (5) it may be fairly stated that about 100,000 gallons per acre per day may be filtered through coarse sand filters similar to Tanks No. 1 and Nos. 12, 13, and 14, and results obtained more than satisfying the conditions of any standard of sewage purification yet laid down. Such filters may occasionally require either periods of comparative rest during which the amount of sewage applied would be much less than the average, or, in some cases, of absolute rest; it will doubtless be found advantageous to turn under the top layers of the filtering material, while in time it may be necessary to renew them. This rest period may be usually easily obtained in the summer by having areas to which sewage is applied for irrigation purposes only, and with due reference to the best commercial return from the growing crop. The summer season, too, with its higher temperature, is the time when a given period of rest may be expected to give the most thorough recuperation. In this view broad irrigation may be considered an adjunct of purification by intermittent filtration.

(7) Experiments with *Bacillus prodigiosus* indicate that coarse sand filters, when filtering at the rate of 60,000 gallons per acre per day and upward, may allow a few of the more hardy varieties of bacteria to pass through; but with fine sand filters, filtering say 20,000 to 40,000 gallons per acre per day, it is uncertain that any bacterium whatever is hardy enough to survive the passing through.

(8) Filters of either clean fine sand or of river silt may be expected to purify at least 30,000 gallons per acre per day so thoroughly as to produce an effluent organically far superior to ordinarily pure waters, and in which the number of bacteria per unit volume is much less than in such water. Whether the few bacteria actually found in the effluent experimented upon, came through from the surface, or whether they are derived from the under-drains, or from bacteria developed in the lower portions of the filters, is uncertain. It is possible that at times, even with the fine sand filters, a few come through.

The actual record of Tank No. 2, fine sand, for the third and fourth years of its service, 1890 and 1891, shows that it filtered an average of 49,360 gallons daily, removing 97.5 per cent. of the organic matter and at least 99.99 per cent. of the bacteria.

(9) With fine river silt, it appears that the best way to apply the sewage is either in trenches which have been excavated and filled with coarse sand, or possibly to such areas the upper foot or foot and a half of which has been covered with coarse sand into which the daily application may sink in a short time.

(10) The advantages of applying sewage to trenches excavated in the original material of an ordinary field, and filled in with clean, coarse sand, are as follows: (*a*) If sewage is applied over the whole surface, the finer particles are likely to be taken up by the sewage as it flows over the field, and deposited in the interstices in such manner as to soon choke the inter-spaces; if applied in winter to the upper layers of such material, by reason of nearly continual saturation it is more liable to freeze than would be the case if open so that sewage readily passed into and through the spaces; (*b*) with trenches about one foot wide, two feet deep, and five feet apart, filled nearly full of coarse sand, we have provided a medium which will readily receive the sewage and quickly take it below the surface. The area of fine material on the sides and bottom of the trenches is equal to the area of the whole surface of fine material in the field; to this equivalent area the sewage comes not only freed from sediment by straining through the coarse sand, but it further comes to it with such slow motion as not to disturb the particles of fine material; the underground surface of the original fine material of the field, therefore, remains permanently open to receive the sewage; (*c*) the surface of sand occasionally requiring renewal is at the same time limited to one-fifth; and (*d*) this one-fifth portion can be materially assisted, when necessary in cold weather, by covering the trenches with boards.

(11) Fields covered with an impervious or nearly impervious soil at the surface, but having coarse sand or gravel subsoils, can be provided with trenches cut through the poorer filtering material near the surface, and more efficient filtering areas made than when prepared in the usual manner.

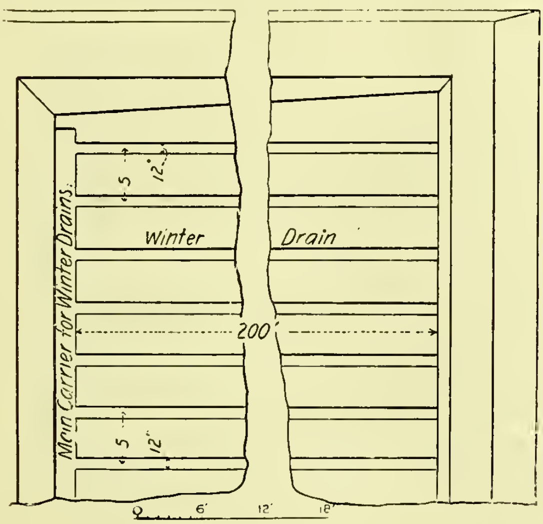
(12) These trenches, filled with coarse sand, may be the best method of arranging filter areas in the colder climate of the Northern States. With them, sloping areas can be utilized without the expense of levelling. The field at Lawrence has a maximum slope of about 1 in 10; while the trenches are arranged in reference to the contours in such manner as to slope from 1 in 50 to 1 in 100.

(13) As a deduction from (12) and what has preceded, it may be concluded that when in extremely cold climates, liable to heavy snow-

falls, it is found desirable to use full area coarse-sand filters, they may be efficiently operated in winter by arranging the surface before the beginning of cold weather in trenches, somewhat after the manner described in the foregoing, and providing board covers for the same, to be removed and stored in the spring, and at the same time the surface levelled for ordinary full surface application during the warm months. For moderate winter climates, however, the filter areas may be operated without any protective covering at all.

A suggestion for a system of covered winter absorption drains on a level area is given in plan and section by Fig. 24.

(14) The mechanical separation of a portion of the sewage which takes place in the coarse-sand trenches referred to in 10 and 11 is merely an incident of intermittent filtration which under certain conditions favorably modifies the result.



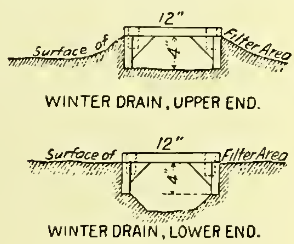


FIG. 25.—SUGGESTION FOR COVERED WINTER ABSORPTION DRAINS.

(15) In estimating the relative value of chemical versus filtration processes of purification, the practical question arises as to which process may be expected to furnish an effluent least adapted to support the life of bacteria. Experiments upon the effluents from the coarse-sand filters indicate that the organic matter remaining therein is in no case well adapted to support bacteria.

(16) The further practical question arises in relation to the use of the purified effluents from filtration areas for drinking. The answer is: (*a*) That judging by chemical analysis alone, there is nothing in the effluents known, or even suspected by chemists, to be harmful; (*b*) there are, however, a few bacteria which survive passage through the coarse-sand filters, and until we are able to say that none of these are disease-producing varieties, the drinking of the undiluted effluents from the coarse-sand filters cannot be considered permissible; (*c*) the

amount and conditions of dilution which may be necessary to render such effluents comparatively safe, depend upon so many elements, that a rational opinion relative to the probable degree of safety in any given case can only be given by an expert after an examination of all the attendant circumstances; (*d*) although not absolutely proven, there are nevertheless strong reasons for believing that the effluents from fine-sand filters are entirely free from bacteria of every sort and kind, and if, on further study, it turns out that this is true, so far as present

Fig. 26. — Cultivated Filtration Area with Absorption Ditches, Luton, England.

information goes, there is no reason to be urged against drinking the effluents from such filters.

No reference has been made in this chapter to the partial cultivation of intermittent filtration areas by the use of the ridge and furrow system, which has been employed in England with more or less success. The new views which we derive from the Lawrence experiments seem to indicate that inasmuch as cultivation would not only interfere with the primary object of sewage purification, but furthermore, cannot as a rule be made profitable on such areas, there is no reason why it should be attempted. The statement made by Mr. Clarke, in 1885,* that "if it is proper to dedicate land to use as a park for the pleasure of the public, there is no reason why it may not be dedicated to sewage puri-

* Report of Eliot C. Clarke to Mass. Drain. Com., p. 127.

fication in order to preserve health," is considerably enforced by the new views. Fig. 25, however, illustrates a cultivated filtration field

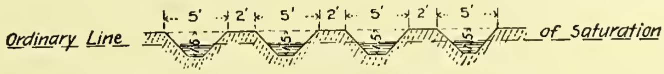


FIG. 27.—METHOD OF ADAPTING INTERMITTENT FILTRATION AREA TO CULTIVATION, BY MEANS OF ABSORPTION DITCHES.

at Luton, England, as photographed by Mr. Clarke, in 1885, and Fig. 26 shows a similar filtration area in section, it being common in England to adapt filtration areas to cultivation by means of absorption

FIG. 28.—SECTION OF HIGH GRADE INTERMITTENT FILTRATION BEDS.

ditches like those shown in these figures. Fig. 27 is designed to show the method of constructing a high grade of intermittent filtration beds with coarse sand as a filtering material and with tile underdrains.

CHAPTER XV.

SUB-SURFACE IRRIGATION.

Sub-surface irrigation is a useful modification of broad surface irrigation applicable to relatively small quantities of sewage, as from isolated houses, hospitals, prisons, asylums, summer hotels, manufacturing establishments, or any other place without access to the sewerage system of a large town. Originally introduced by the Rev. Henry Moule, the invention of the automatic flush-tank by Rogers Field gave it at once a utility that rapidly brought it into public notice. In spite, however, of its being an English invention it has probably been more extensively used in this country than there, due largely without doubt to its early introduction by Col. Geo. E. Waring, Jr., M. Inst. C. E., and its persistent advocacy by him, Mr. Philbrick, and other American sanitary specialists. At present the tendency is to use it less here than formerly, before the ease and certainty with which broad surface irrigation and intermittent filtration can be used in our climate were thoroughly understood. It is, nevertheless, a useful system under certain circumstances, and as such deserves brief notice in a work of this character, though by reason of its having been fully described by others, little more will be attempted than to point out the chief sources of information.*

Mr. Olcott, in his paper, The Small-pipe Underground Intermittent System of Sewage Disposal, has given in a tabulated statement the detail of 37 small sub-surface irrigation systems constructed at various places, the most of them for single houses ; he states that he has constructed about 70 similar works in all.†

* These are (1) Waring's Sewerage and Land Drainage, chap. xxvii., sub-sec., The Disposal of Household Wastes, p. 287 and following ; (2) Gerhard, The Disposal of Household Wastes ; (3) Philbrick, The Disposal of Sewage in Suburban Residences, pamphlet reprint; also in The Sanitary Engineer, vol. vii. (1883), pp. 530 and 534 ; (4) paper by Geo. E. Olcott, The Small-pipe Underground Intermittent System of Sewage Disposal, in 11th An. Rept. N. Jer. St. Bd. Health pp. 79–88 ; and (5) a paper by Col. Waring, Sewage Disposal for Isolated Houses, in Am. Arch., March 12, 1892.

† Tabulation includes information in reference to each of the 37 examples cited on the following points :

(1) For whom and where constructed.
(2) Number of persons contributing.
(3) Approximate first cost.
(4) Length of time in use at date of making the tabulation.
(6) Answer to the question, Is system free from nuisance ?

As the result of this experience, Mr. Olcott indorses the following views, as to the cost, etc., of sub-surface irrigation plants on a small scale, expressed by Dr. J. W. Pinkham, of Montclair, N. J., in a paper before the New Jersey Sanitary Association in 1884, from which Mr. Olcott's statistics are chiefly quoted, namely:

(1) The first cost for a family and house of average size is about $200.
(2) The cost of annual maintenance is about $10 for such a house.
(3) The ground selected should be free from shade and may be either garden or lawn.
(4) By means of this system all liquid sewage, from the smallest dwelling-house or the largest institution, may be effectually disposed of without nuisance and without peril to health.
(5) This system should take the place of cesspools in all suburban and country places which have sufficient ground for the distributing pipes.

A reference to the several sources of information here indicated will, it is believed, furnish whatever is needed by any one thinking of using this system.

(7) Answer to the question, Is all house waste satisfactorily disposed of?
(8) Answer to the question, Have stoppages occurred?
(9) Answer to the question, Is the soakage area underdrained?
(10) Answer to the question, Is the soakage area superficially dry?
(11) Miscellaneous statements from the parties for whom constructed, including individual opinion as to success of operation, etc.

CHAPTER XVI.

THE DISPOSAL OF MANUFACTURING WASTES.

Classification.

The English Rivers Pollution Commission gave the disposal of manufacturing wastes extended consideration in their First, Third, Fourth, and Fifth Reports. The information there given is the basis of all the exact knowledge of the subject which has thus far been obtained. Taking their several Reports as a basis, manufacturing pollutions may be classified under the following heads:

(1) Pollution by calico dye-works, print-works, and bleach-works.

(2) Pollution by flax steeping and by linen and jute bleaching and dyeing.

(3) Pollution by starch-works.

(4) Pollution by paper mills.

(5) Pollution by alcohol distilleries.

(6) Pollution by sugar-refining and glucose works.

(7) Pollution by petroleum refining.

(8) Pollution by woollen works, hat works, etc.

(9) Pollution by chemical works.

(10) Pollution by tanneries.

(11) Pollution by silk-works.

(12) Pollution by collieries and coal washing.

(13) Pollution by iron and other mining operations.

(14) Pollution by iron-works, rolling mills, and other heavy metal-works.

(15) Pollution by the cutlery trade.

(16) Pollution by iron and steel wire, tin-plate, and galvanizing works.

(17) Pollution by brass foundries.

(18) Pollution by German silver and electro-plate works.

Manufacturing Wastes—How Purified.

It is unnecessary to consider in this place the large amount of detailed information given by the Commission in these reports. In the chapter on the Pollution of Streams we have already given some of the main facts of stream pollution in this country, and we may simply

refer to these reports of the English Commission as furnishing a larger body of detailed information than can be obtained in any other place.* The Commission suggests for the purification of manufacturing refuse substantially the same treatments as are available for the purification of town sewage, namely: Chemical precipitation, broad irrigation, and intermittent filtration, and the general conclusion may be drawn, that the choice of method, in any given case, will depend largely upon special conditions, the same as in the purification of town sewage. A considerable number of large manufacturing establishments in England and Scotland have constructed purification plants, and in some cases the utilization of the refuse matters has more than repaid the cost of constructing, maintaining, and operating the same.†

Relative Danger to Health.

As a general proposition it may be stated that a large portion of the refuse of manufacturing processes is less dangerous to health than domestic sewage, when turned into streams, for the reason that it does not contain, *per se*, the germs of infectious diseases. It is nevertheless true, that the refuse of different manufacturing operations varies greatly in respect to polluting qualities, as well as the facility with which it can be purified. For instance, the refuse from woollen scourings is frequently large in amount and difficult to treat; the washings from foul rags in paper-making may also be viewed with suspicion, but the vegetable dyes, acids, and alkalies are not especially dangerous when considerably diluted. Some chemical reagents, which occur as refuse from manufactories, may even act as precipitants when turned into streams, and in that way conduce to a partial purification of the stream below the point of their inflow. This fact, however, cannot be construed into an argument in favor of indiscriminate pollution of streams by manufacturing refuse.

Difficulties in the way of Purification.

Again, the satisfactory purification of manufacturing wastes is, at many mills, rendered exceedingly difficult on account of the large quantity of water with which they are mixed. In many cases the use of water is unnecessarily large, and the first step toward the general purification of manufacturing refuse will undoubtedly be for the manufacturers to learn to use less water and to separate their drainage in such manner that water only slightly fouled by use may go back into

* See 7th Rept. Mass. St. Bd. Health for *résumé* of this information.

† For sample plans of extensive plants designed specially for purification of manufacturing wastes, see 4th Rept. of Riv. Pol. Com., p. 61, *et seq*.

the stream, while the more seriously polluted drainage is discharged into sewers, or purified by special appliances at the works, as the case may be.

American Examples.

Thus far in this country manufacturers have not, except in a few instances, been compelled to purify their own polluted wastes, and inasmuch as few have undertaken the purification, of their own volition, very little experience under American conditions has thus far been gained. A few unsatisfactory cases, derived from Mr. Clarke's report to the Massachusetts Drainage Commission, may be cited:

(1) The Wanskuck Mills, Providence, R. I., are among the largest of those in the United States making woollen and worsted goods. Until 1881 the dirty water resulting from the different operations, amounting to about 400,000 gallons per day, flowed directly into West river. The yearly amount of refuse contained in this water included about 64,000 pounds of dyestuffs, 100,000 pounds of alkali, 4,000 pounds of acid, 53,000 pounds of fuller's earth, and 400,000 pounds of grease. A dyeing and bleaching company below brought a suit against the Wanskuck Company on account of the serious injury to its operations by the pollution of West river. After protracted litigation the Supreme Court granted a permanent injunction forbidding such pollution. In compliance with this injunction attempts have been made to purify the waste water before permitting it to enter the river. At first, filtration through land was tried. The foul liquid was pumped on to a tract of gravelly land near the mills, about forty feet above the river. An acre and a half was prepared by making furrows four feet apart on the surface. The liquid was made to flow during the morning through the furrows on one-half of the land, and during the afternoon through those on the other half. For about three weeks this process was successful, as the water filtered through the land and came out clean. After this time the surface of the furrows became clogged, the water would not soak away fast enough, and the process was abandoned. It is stated, however, that a few days later the water had disappeared, and the film of sediment which had choked the ground dried, cracked, and curled up, showing clean sand underneath it. It is probable that after this interval, if the water had been applied again, it would have filtered away as before, and the process might have been continued intermittently by allowing occasional periods during which the film of sediment could dry and crack. When a considerable amount of sediment had accumulated, and had been allowed to dry, it easily could have been broken up with tools and thrown upon the ridges between the furrows. As the liquid filtered for three weeks before the surface of the ground became clogged, whereas it took less than a week for the film of sediment to dry and crack, continuous purification could have been effected by the use of double the quantity of land, divided into two plots, used alternately. Two gentlemen, one of them the superintendent, who observed the experiment, are now of the opinion that this method would have proved sufficient. At the time that the first experiment was thought to be a failure purification by precipitation was adopted, and has been continued since. A set of six connected basins was excavated on the land previously used for filtration. Two of these basins, about 30 feet by 60 feet each, were connected with four others about 75 feet by 220 feet each, all being 5 or 6 feet deep. About a barrel of lime to 100,000 gallons is added to the waste water at the mill before pumping. This addition is made rudely, the lime not being previously ground or even slaked. The water flows through one of the smaller basins, in which most of the deposition takes place. Leaving the small basin it flows through the four larger ones successively, where further deposition takes place. To the eye, the effluent from the last basin looks about as dirty as the water which leaves the pumps. A decided smell from the basins is noticed in muggy weather, and as a whole the result is not satisfactory. As such processes

have proved effective elsewhere, the failure must be due to defects in the practical management of the process. For a while after it was attempted, sulphate of alumina was used as a precipitant. The cost of this chemical, which amounted to about $7 per day for each 100,000 gallons, or $6,000 per year for the whole amount treated, was considered so great as to preclude its use. The sludge which is cleaned from the basins is found to be commercially valueless. It is said to have proved beneficial when applied to grass in the neighborhood, but in practice it is found that, although it is given away, nobody comes for it a second time. It is thought that of the whole liquid waste 50,000 gallons would comprise all of the water used in washing wool and the greater part of the polluting refuse.

(2) A method of wool scouring is practised in the Lorraine Mills, Saylesville, R. I., by which the grease is preserved, and most of the other dirt is eliminated from the wash water before permitting it to escape. The wool is washed in a machine having three bowls. . . . Six hundred pounds of wool are washed at a time, and pass successively from bowl 1 to bowls 2 and 3. When a new charge of dirty wool is put into bowl 1, the water previously used in bowl 2 is transferred to bowl 1, that from 3 is put into 2, and clean water is used only in bowl 3. Thus, bowl 1, in which the wool is first washed, always contains water which has been used twice before, and bowl 2 that which has been used once. The amount of clean water added in bowl 3 at each washing is about 400 gallons. To this about 27 pounds of soap are added, and a small quantity of free lye. Six hundred pounds of wool therefore are washed with about 400 gallons of water, which is very much less than is commonly used for the purpose, and probably is as little as will accomplish the work. The resulting product is about 300 pounds of clean wool. The water from bowl 1 is drawn off into a "cooler," which is a pit about 30 feet across on top, dug in the ground. In this the water cools, and a small part of it evaporates or leaches into the ground. Most of it flows into a tank in the "save-all" house, from which it is pumped into three smaller tanks for treatment. These latter are about 7 feet square by 5 deep. In them the alkaline liquid receives a small quantity of sulphuric acid. This causes the greasy particles to separate from the water and rise as foam. The water below is then drawn off, and escapes into the river. It is clear, and about the color of amber. It has an odor like that of wool, and is somewhat acid. The greasy scum is drawn off upon four artificial filters of gravel, having a superficial area of about 200 square feet each, and two feet depth of filtering material. The scum solidifies somewhat upon the filters, and is shovelled into bags, which are put between sheet-iron plates, in a press contained in a tight box which can be filled with steam. The grease flows from the bags as oil, and what remains in the bags is reduced to "soot-cake." The oil is somewhat further refined, and then barrelled for the market. When cool, it has the consistency of lard or common soap-grease, and is of a reddish color, with an odor of wool. It is used either for stuffing leather, or as a lubricant, or in the manufacture of soap, etc. The "soot-cake," which is principally dirt, contains as it comes from the press about 50 per cent. of moisture. It has been analyzed by two chemists, one of whom reports it valueless, and the other as having some manurial value. From 18,000 pounds of wool there are obtained a ton of grease and 1,200 pounds of "soot-cake." The cost of the plant for extracting these, not including buildings, was $2,500. The process has only recently been put in operation, but is thought to be remunerative.

(3) Two mills in Millbury, Mass., each scouring about 1,000 pounds per day of wool in the grease, retain the first scour, which is supposed to contain about five-sixths of the dirt, thus lessening in that proportion the pollution which they otherwise would cause to the river. The first scour is retained in vats, which are cleaned periodically, and their contents used as a fertilizer. In these two cases the process is thought to be a paying one.

(4) The woollen mills of Robert Bleakie & Co., at Hyde Park, Mass., employ about 275 operatives. All refuse from closets, wool scouring, and dyeing goes into a settling basin, from which the effluent goes into the stream. About 3,000 lbs. of wool are scoured daily with about 40 lbs. of soda ash, and are dyed chiefly with ground dyewoods. The wool shrinks in cleansing from 50 to 60 per cent., so that the refuse amounts to over 1,500 lbs. daily. The settling basin through which the

waste water flows, as shown by the accompanying cut, Fig. 29, consists of a cemented structure 80 feet long by 10 feet wide and 3: 5 feet deep. A large amount of solid refuse is intercepted by this, the heavier portions being retained in the bottom of the basin, and the greasy scum floating on top. The effluent, however, is still very dirty. The proprietor cleans out the basin at intervals, and uses its

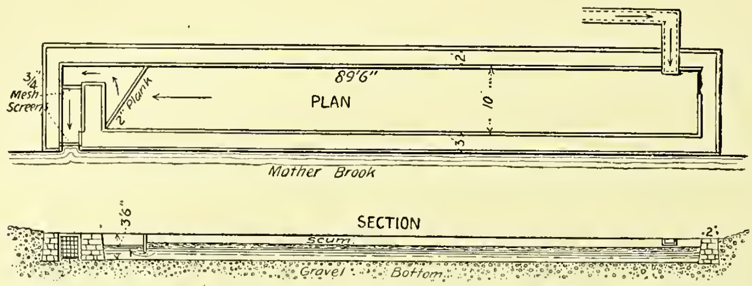


FIG. 29.—SETTLING BASINS AT WOOLLEN MILLS, HYDE PARK, MASS.

contents to fertilize his land. He estimates its value for this purpose at several hundred dollars per year.

(5) Next to the pollution caused by wool washing, the refuse from tanneries seems to cause the most trouble. There are very few cases in which attempts have been made to purify this refuse. The drainage from a tannery can be clarified chemically by the use of salts of iron, sometimes in conjunction with lime, as precipitants. At one place which I visited in England, a little sulphate of iron was first added to the drainage, uniting with the tan in forming tannate of iron, which was afterwards precipitated by the addition of lime-water from the lime-vats. The liquid, which was nearly colorless, was then filtered through gravel. Where the

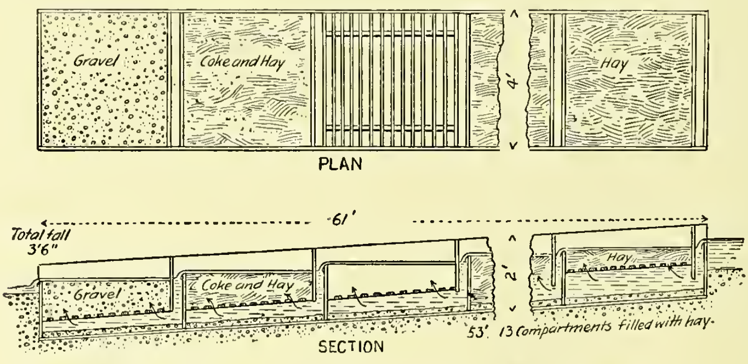


FIG. 30.—MECHANICAL FILTER AT TANNERY, WINCHESTER, MASS.

water contains a great deal of tan bark, it probably would be necessary to intercept this in some way before purifying the water by intermittent filtration, because otherwise the bark would clog the surface of the ground. At Maxwell's tannery, in Winchester, a mechanical filter, Fig. 30, to strain out the bark and coarse lime, has lately (1885) been put on trial. This consists of a wooden box, about 4 feet wide, 2 feet deep, and 60 feet long. This is divided into compartments which are filled with hay, through which the water filters. The effluent generally is clear, but of a deep mahogany color.

A Study of Paper-Mill Wastes.

In 1885, Professor Wm. Ripley Nichols examined, at the request of Mr. Clarke, a number of samples (eight in all) of the waste material from the paper-mill of Messrs. C. F. Crehore & Son, situated at Newton Lower Falls, Massachusetts. At this mill domestic rags and tarred hemp junk are made into card and press paper for mills. The stock is first cut and dusted, which removes part of the waste in a dry state; it is then boiled with lime to saponify the dirt, and bleach out the color. The waste water from this process is called bleach liquor. The stock is then washed in a paper engine, where it is passed under a heavy roller with steel blades, acting against a bed-plate also set with steel blades, the whole so arranged as not to cut the stock but merely to separate the fibres. A constant stream of water passes through the paper engine for an hour or more. The effluent, which is called wash-water, at first looks very dirty as it leaves the engine, but toward the end of the operation it appears to flow away clean. Sand-boxes in the bottoms of the washing engines receive the heavier particles, such as sand, dirt, buttons etc., removed from the stock.

The samples submitted to Professor Nichols, comprised: (1), solid refuse from the "sand-boxes;" (2), samples of "bleach-liquors;" (3), samples of "wash-waters." The following is from Professor Nichols' report:

The details of the examination of the various samples and such recommendations as I am able to make are as follows:

1. MATERIAL FROM SAND-BOXES.

The dirt from the "rags" sand-box, after draining off the liquid, weighed 252 grammes while wet, and 98 grammes when dry. In bulk, it was mainly fibre; by weight, the larger part was sand, buttons, metallic hooks, pins, paper-fasteners, wire, etc. Expressed in per cents. we have:

	Per cent.
Water	61
Buttons and other heavy dirt	24
Fibre and light dirt	15
	100

Calculating on the dry material we have:

	Per cent.
Buttons and heavy dirt	61
Fibre and light dirt	39
	100

The fibre and light dirt burned readily, leaving about half its weight of ash, or more exactly we have:

	Per cent.
Volatile and combustible matter	47.72
Ash	52.28
	100.00

	Per cent.
The "fibre and light dirt" contained matter soluble in ether	1.29
Matter soluble in ether after treatment with hydrochloric acid	5.80
Phosphoric acid	0.37
Nitrogen	0.59
Potash, not determined.	

In my opinion there is not grease enough to pay to extract, or fertilizing matter enough to give a commercial value to the material as manure. There is, however, no reason why it should be discharged into the stream. If removed from the sand-boxes and dried, either by waste heat, if any is available, or by exposure to the air, it can then be burned under the boilers. This is, in my opinion, the best disposition to make of it. It would, no doubt, be better to arrange for the settling of the heavier portion, containing bits of metal, etc., and dry and burn only the lighter portion. The heavier portion could be simply mixed with the ashes of the establishment without harm and be disposed of with them.

2. MATERIAL FROM THE "ROPE" SAND-BOXES.

The sample received weighed wet 67 grammes, dry 13 grammes. When dry it burned readily, leaving less than half its weight of ash. We have, then,

	Per cent.
Water	81
Dry fibre and dirt	19
	100

The dry fibre, etc., consisted of:

	Per cent.
Volatile and combustible matter	63.6
Ash	36.4
	100.0

Ether extracted 18.67 per cent. of a tarry matter which burned with a smoky flame. The fibre contained:

	Per cent.
Phosphoric acid	0.42
Nitrogen	0.10

The best disposition that can be made of this material is the same as that suggested in the previous case.

3. BLEACH-LIQUOR FROM THE RAG BOILERS.

This was a frothy, dark-colored, turbid, strongly alkaline liquid containing a large proportional amount of organic matter. The results of a partial examination appear in the table. If this liquid had to be disposed of by itself, the best method would probably be to evaporate it under the grate-bars or in some other way by waste heat if possible. It would give about 9 or 10 per cent. of its weight of a thick syrup, which could then be burned, and by its burning return part of the heat required to evaporate it. As, however, the first portions of the wash-water are unfit to discharge into the stream, it would probably be better to mix all the liquors together for treatment.

4. BLEACH-LIQUOR FROM ROPE.

This resembles the previous sample in general respects and might be treated similarly.

5, 6, 7, 8. WASH-WATER FROM RAGS AND FROM ROPE.

Samples 5 (rags) and 6 (rope) were taken 10 minutes after washing began, and samples 7 (rags) and 8 (rope), after 2 hours. The latter, although turbid and unin-

viting to the eye, might be discharged into the stream after a simple process of filtering through sand or sand and gravel. The first portions of the wash-water are, however, too foul to be thus discharged. I have made a number of experiments with various chemical precipitants; with the stronger liquors very little satisfaction was obtained. With the weaker liquors, or with a mixture of the strong and weak together, better results were obtained, but the method would be expensive and the effluent ought not to go into a stream used for water-supply. In my

TABLE No. 67.—EXAMINATION OF VARIOUS SAMPLES OF REFUSE FROM CREHORE'S PAPER MILL.

(Parts per 100,000.)

	Unfiltered.		After filtering through paper.		Alkalinity expressed as lime.	Organic nitrogen.
	Total solids.	Volatile.	Total solids.	Volatile.		
RAGS.						
Drainings from dirt	......	......	......	......	73.2	.....
Bleach-liquor	7326.0	5032.0	7222.0	......	749.6	360.0
Wash-water after 10 minutes	537.5	......	393.0	......	120.9	.....
Wash-water after 2 hours	18.5	11.5	11.0	4.5	0.5	.....
ROPE.						
Drainings from dirt	......	......	.....	......	13.0	.....
Bleach-liquor	8193.0	......	8120.0	5144.0	178.0	51.0
Wash-water after 10 minutes	492.5	......	369.0	.....	57.0	.....
Wash-water after 2 hours	38.0	28.0	18.0	9.0	0.8	...

opinion, the best way of disposing of these liquors is by "intermittent downward filtration," through a sufficient amount of land. Judging from the published experience in other places this would be quite practicable, but I do not feel wholly sure of the success with the bleach-liquor from the ropes, as the organic matter therein contained is not as readily oxidized as is that from the rags. Experience might show that a larger area of land was necessary if this liquid were mixed with the rest than is usually required, but I think it would be better to evaporate this liquid as indicated above. The amount of heat required would not be great. I do not possess accurate information as to the amounts of the various liquids of which samples were sent to me; but I assumed, on the strength of rough estimates which you gave me, that the daily discharge is approximately made up of:

700	gallons of bleach-liquor	(Rags.)
700	" " " "	(Rope.)
50,000	" " wash-water	5
50,000	" " " "	6
150,000	" " " "	7
150,000	" " " "	8

After the samples had been in my laboratory for more than two weeks, and had, consequently undergone some chemical change, I made a mixture in this proportion and had it analyzed with the results which follow, and which represent, approximately,* the character of the present discharge:

Total solids in solution	120.	parts in 100,000
Organic and volatile matter	80.	" " "
Inorganic matter	40.	" " "
Solids in suspension	74.	" " "
Organic and volatile	30.	" " "
Inorganic	44.	" " "

* ANALYTICAL NOTE.—These results of analyses vary somewhat from those calculated from Table 67, mainly because the liquors had undergone some change since the first determinations were made, but partly because, in liquids of this character (*i.e.*, containing caustic lime), some of the determinations, such as that of the total solids, do not have a high degree of accuracy.

Alkalinity as lime	25.4	parts in 100,000
Ammonia	0.833	" " "
Albuminoid ammonia	3.050	" " "
Total organic nitrogen	5.353	" " "

In the absence of more definite knowledge of the composition which the united waste liquids would have, and in the absence of knowledge as to the land which may be available, it is impossible to estimate accurately the amount of land required for treating the liquid. Of land favorable for the purpose, perhaps some three or four acres would be required. The liquid is rather alkaline to be used for irrigation, but if exposed to the air would lose some of its alkalinity, or if there were acid refuse from some other establishment which could be mixed with it, it would be an advantage. To neutralize 400,000 gallons of a mixture such as described above would require 1,500 lbs. of oil of vitriol. A portion of the organic matter would then settle out as sludge (which could be filtered off, dried, and burned), but the lime would go into the effluent as sulphate of lime, which would be of disadvantage to the stream as a source of water-supply.

TABLE No. 68.—EXAMINATION OF VARIOUS SAMPLES OF REFUSE FROM CREHORE'S PAPER MILL.

(Pounds to 1,000 gallons.)

	Unfiltered.		After filtering through paper.		Alkalinity expressed as lime.	Organic nitrogen.
	Total solids.	Volatile.	Total solids.	Volatile.		
RAGS.						
Drainings from dirt	....	.....	.....	.....	6.1	.....
Bleach-liquor	611.2	419.8	602.3	.....	62.5	30.0
Wash-water after 10 minutes	44.8	.....	32.8	.....	10.1	.....
Wash-water after 2 hours	0.05	0.96	0.92	0.47	0.04	.....
ROPE.						
Drainings from dirt	.....	.....	.....	.....	1.1	.....
Bleach-liquor	683.5	.....	677.3	429.0	14.8	4.3
Wash-water after 10 minutes	41.1	.....	30.8	.....	4.8	.....
Wash-water after 2 hours	3.2	2.3	1.5	0.75	0.7	.....

CHAPTER XVII.

ON THE TEMPERATURE OF THE AIR AND OF NATURAL SOILS, AND ITS RELATION TO SEWAGE PURIFICATION BY BROAD IRRIGATION AND INTERMITTENT FILTRATION.

Empirical Tendency of English Practice in Sewage Disposal.

In examining the voluminous literature of sewage purification by broad irrigation and intermittent filtration in England, one is forcibly struck with the purely empirical tendency of current practice there, and, in so far as this tendency has kept the development of this branch of sewage purification in the line of well-ascertained observation and experience, it is by no means to be deplored; because there is in the beginning of all new sciences or arts a period when conservative empiricism is in reality the highest form of knowledge put in order, that is to say, such empiricism is in reality the position of the true scientist. In the course of time, however, as the body of well-ascertained fact becomes greater, theory and deduction may properly come in as legitimate tools in the hands of those who are interested in the scientific investigation of problems in physics, and it is in this latter view that the following chapter is submitted for comment and criticism.

Information still Lacking.

The experiments of the Massachusetts State Board of Health have extended our knowledge of the kind of material best suited for sewage purification by filtration through soils considerably beyond what was previously known. Indeed, so extensive is the advance that we are able to predict results, as noted in a previous chapter, to this extent that, with a given material, we can say beforehand approximately what degree of purity will be attained for a given quantity of sewage applied per unit of area. We still lack definite information as to the extreme conditions of climate under which purification by broad irrigation and intermittent filtration may be effected, though the results recorded in the Twenty-third Annual Report of the Massachusetts State Board of Health, and given in Chapter XIV., help out somewhat; and it is with a view of still further supplying the deficiency that the information embodied in the following has been got together.

The Massachusetts experiments have demonstrated, moreover, that under proper conditions the nitrification of sewage will proceed during cold weather, although not as rapidly as in warm weather.* The detail of what can be actually accomplished in this particular is given, as we have seen, in the Special Massachusetts Report, and in the Annual Report for 1891, already referred to.

Temperatures of Air and Sewage at Lawrence.

In order to illustrate the question of temperatures at Lawrence, where the experiments have been carried on, Tables Nos. 69 and 70, derived from the Special Report, are given. The winter of 1887–88, when the mean temperature for January was 15.46°, is stated to have been the coldest in 20 years. It was found necessary, because of the low temperature at which the sewage arrived at the experiment station, to warm it by passing a hot water-pipe through the measuring tank. In reference to this it may be noted as a very important point

Table No. 69.—Mean Maximum, Mean Minimum, and Mean Temperature of Air at Lawrence, from November to March, Inclusive, During the Winters of 1887–88 and 1888–89.

(Fahrenheit°.)

Month.	1887–88.			1888–89.		
	Mean max.	Mean min.	Mean.	Mean max.	Mean min.	Mean.
November	47.16	28.30	37.73	48.40	31.30	39.85
December	35.54	20.87	28.20	38.09	21.45	29.77
January	24.61	6.32	15.46	39.77	23.00	31.38
February	35.03	12.24	23.63	32.75	11.82	22.28
March	39.13	20.39	29.76	45.38	26.55	35.96

in the discussion that the winter temperature of the sewage was considerably reduced by reason of the pipe conveying it from the sewer to the experiment station passing along the bed of the Merrimac river for nearly half a mile. The difference caused thereby is shown in Table No. 70.

In reference to Table No. 70 it may be stated that for the purpose of comparing temperature of effluent with the temperature of sewage the effluent from Tank No. 1 has been selected. This tank is composed of a filtering material of 9,000 gallons of clean, coarse mortar sand of even grain, in which the voids were found to equal 36 per cent. of the whole. When saturated with water and allowed to drain there remained 12 per cent. of the total volume, which was filled with water, and 24 per cent. containing air, the sand occupying 64 per cent. of the total space.

As shown in Table No. 70 the mean temperature of the sewage, as

* For statement of winter purification in detail, refer to Chapter XIV., Article on The Effect of Frost and Snow upon Intermittent Filtration at Lawrence, p. 280, and following.

TABLE No. 70.— MAXIMUM, MINIMUM, AND MEAN TEMPERATURES IN MAIN SEWER AT LAWRENCE, THE SAME FOR SEWAGE AS DELIVERED TO FILTER TANKS AND FOR EFFLUENT FROM TANK No. 1, FROM JANUARY, 1888, TO APRIL, 1889, INCLUSIVE.*

(Fahrenheit °.)

	Temperature in main sewer.			Temperature of sewage as delivered to filter tank.			Temperature of effluent from Tank No. 1.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1888.									
January	—	—	46.5	37	34	35.3	36	35	35.7
February	44	36	41.6	65†	35	47.0†	37	35	35.7
March	44	36	40.5	80†	51†	60.6†	42	35	36.6
April	51	45	47.2	46	36	43.6	46	40	42.2
May	57	51	53.2	57	45	51.8	57	47	52.0
June	63	57	59.4	73	58	65.9	73	58	64.1
July	66	61	63.7	73	65	69.8	74	68	71.0
August	68	65	67.1	74	69	71.1	75	71	73.3
September	67	62	64.3	71	55	64.1	74	61	68.4
October	59	54	56.3	53	45	47.8	61	51	55.1
November	52	50	51.0	50	38	45.0	54	43	49.1
December	48	45	46.5	46	41	44.7	44	39	44.1
1889.									
January	47	44	45.9	45	44	44.7	41	38	39.6
February	48	43	44.5	46	44	44.9	39	37	37 6
March	47	40	45.2	44	33	36.6	41	36	39.6
April	57	45	49.5	53	39	46.1	53	40	45.7

* The maxima and minima of this table are not true maxima and minima as derived from maximum and minimum thermometers; they are merely the highest and lowest daily readings, as taken from the tabulations in the Special Report. † Sewage warmed artificially.

applied to the filters in January, 1888, was over 11° below that of the sewage in the main sewer. In the winter of 1888–89 sewage was applied at a temperature of about 45°, which was but little below the temperature of the main sewer, except in March, when the temperature of the applied sewage ranged from 44° to 33°, with a mean of 36.6°. The mean temperature of the air for February of this year was 22.3°, as shown in Table No. 69.

Without going into an elaborate analysis of the winter results of the Lawrence experiments it will be sufficient for present purposes to state :

(1) That in winters of the mean temperatures of those of 1887–88 and 1888–89, at Lawrence, sewage can be so far purified by intermittent filtration through sand, that probably 40 to 50 per cent. of the nitrogen applied in the sewage will be reduced to nitrates in the effluent.

(2) That to accomplish this, the sewage needs to be applied at about the temperature 42° to 45°, which may be taken as the mean winter temperature in main sewers, although in manufacturing quarters, where hot waste liquids and condensed steam are admitted into the sewers, the temperature of the sewage may be even much higher.‡

‡ See Mr. Gray's Providence Report for temperature in sewers of Paris, where during an extremely cold December in 1879 the mean temperature of the sewage was 43°, with a mean temperature of the air at the same time of 18.3°, and of water of the Seine of 32°.

In another case where a main Paris sewer receives the sewage of a manufacturing quarter, the winter temperature of the sewage was maintained at 53.6° to 62.6°.

(3) The complete nitrification of 50 per cent. of the organic matter represents more than 50 per cent. purification.

Comparison of Air Temperatures at a Number of Places.

Thus far we have comparatively little experience in this country in the winter purification of sewage by either broad irrigation or intermittent filtration on a large scale. We may, however, compare the mean temperatures at a number of places where meteorological records have been kept, with the records of places abroad where winter purification has proceeded without interruption from frost. Table No. 71, following, gives a number of such records.

The column State of Michigan in Table No. 71 may be taken as representing the approximate mean climate of that State. It is introduced for the purpose of showing what may be expected in a typical region in the northern part of the United States. The mean temperatures here given are from a table at page 17 of the 16th Annual Report of the Michigan State Board of Health, the stations represented being in all parts of the State, from Marquette and Escanaba at the North to Detroit, Ann Arbor, and Hillsdale at the South. The mean winter temperatures at Marquette are, however, much lower than the means as here given, and before designing sewage disposal by broad irrigation or intermittent filtration at a point as far north as Marquette, one would need more definite information in relation to local winter temperatures than is afforded by Table No. 71.

Table No. 71.—Mean Monthly Winter Temperatures at the Places indicated in Europe and the United States.

(Fahrenheit °.)

Months.	London.		Dantzic.		Providence.		State of Michigan.		State of Alabama.	
	Mean temperature.	No. of years taken.	Mean temperature.	No. of years taken.	Mean temperature.	No. of years taken.	Mean temperature.	No. of years taken.	Mean temperature.	No. of years taken.
Nov	43.3	50	36.3	81	40.0	48	36.0	10	52.9	30
Dec	39.3		30.0		29.7		26.6	to	46.6	to
Jan	36.5		26.8		26.8		20.6	1	42.9	1
Feb	38.4		29.1		27.3		23.6		49.2	
March	41.0		32.4		33.9		29.8		54.1	
April	46.0		41.2		44.5		44.3		63.5	

In order to illustrate the preceding remark, and also to show the range of the mean in a single State, Table No. 72 has been prepared.

The range in latitude of places in Table No. 72 is from 46°34′ North at Marquette, to 42°17′ North at Ann Arbor, a total range of 4°17′. The lowest mean temperature for any month is found at

TABLE No. 72.—MAXIMUM, MINIMUM, AND MEAN TEMPERATURES FOR THE WINTER MONTHS OF 1886–87 AT SEVERAL PLACES IN THE STATE OF MICHIGAN.

(Fahrenheit °.)

Names of places.	Dec., 1886.			Jan., 1887.			Feb., 1887.			March, 1887.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
Marquette	42	−13	15.7	37	−21	8.0	36	−13	12.0	46	−14	18.7
Escanaba	39	−15	15.0	39	−24	7.6	36	−17	13.0	44	−12	19.2
Mackinaw city	46	0	22.6	42	−14	13.3	41	−12	16.1	39	−10	20.1
Traverse city	46	−1	21.6	39	−15	16.2	46	−15	17.8	48	−7	21.5
Grand Haven	49	−3	22.5	48	−2	20.1	46	−7	24.1	60	7	27.3
Lansing	46	−8	19.6	48	−20	18.2	53	−3	24.4	50	5	27.8
Ann Arbor	45	−2	19.3	52	−12	19.5	53	−3	25.3	51	5	29.1
Detroit	52	3	24.0	54	−3	23.6	54	1	28.2	52	7	31.0

Escanaba in latitude 45°48′ North, for the month of January; the highest mean for the same month being 23.6° at Detroit in latitude 42°20′. The elevations above tide-water range from 930 feet at Ann Arbor to 585 at Detroit; Lansing is 900 feet, Marquette 641; while Escanaba, Mackinaw city, Traverse city, and Grand Haven are all a trifle less than 600 feet. The highest point at which a series of meteorological observations are recorded in Michigan is Reed city, in latitude 43°44′ and 1,016 feet above tide, where in January, 1886, the mean temperature was 17.4°, with the maximum of 44° and minimum of —18° for the same month.

A number of the other States have organized meteorological departments in which the State meteorology is treated somewhat more in detail than by the United States Weather Bureau, and information of the kind indicated in the foregoing as likely to be of use in deciding questions of sewage disposal may be in most cases easily obtained. By way of illustrating the climatology of one of the more southerly States, the means of the winter temperatures at a large number of places in the State of Alabama are also tabulated in Table No. 71. The details of the observations at a few of the stations in that State are given in Table No. 73.

TABLE No. 73.—MINIMUM AND MEAN TEMPERATURES OF THE WINTER MONTHS FOR A SERIES OF YEARS AT SEVERAL PLACES IN THE STATE OF ALABAMA.

(Fahrenheit °.)

Name of place.	Latitude.	Elevation above tide-water, ft.	Mean temperatures.				Minimum for winter.	No. of years' observations included in the means.
			December.	January.	February.	March.		
Huntsville	34° 45′	690	41.8	42.1	42.6	51.3	—0	14
Birmingham	33° 32′	600	49.0	39.1	41.7	50.1	4	3
Tuscaloosa	33° 07′	250	50.4	45.1	48.6	56.6	4	6
Auburn	32° 40′	826	47.8	44.6	50.7	53.6		11¼
Montgomery	32° 23′	219	49.5	48.2	52.8	57.1	5	18½
Troy	31° 50′	450	52.3	46.9	51.3	58.3	14	5
Mobile	30° 41′	35	47.6	50.7	50.2	60.7	11	22

The results of Table No. 73 in comparison with the mean temperature at Lawrence, Massachusetts, as shown in Table No. 69, easily indicate that an exceedingly efficient winter purification of sewage by irrigation and filtration can be attained in the State of Alabama.

The foregoing illustrations of mean winter temperatures in Michigan and Alabama are sufficient to illustrate the value of a well-digested State climatology in connection with the selection of the method of sewage disposal to be used in regions lacking the data of actual experience through a series of years. The variations in climate in different parts of the United States are so extensive, and the range of latitude so great, that definite information of the kind here collected is of the highest value, though for its full utilization we need a series of allied observations in relation to the temperatures of the soil at various depths, such observations of the temperature of the soil furnishing certain modifying corrections which do not appear from a study of air temperatures alone.

Soil Temperature Observations Abroad.

Observations of the temperature of the soil at various depths have been kept at the Greenwich Observatory, the Edinburgh University and at other places abroad for many years, but it is only recently that the subject has received any special attention in this country.

To a number of the Agricultural Experiment Stations established during the last few years may be assigned the credit of beginning a series of studies of soil temperatures of value not only to the agricultural interests of the country, but which also throw considerable light on questions of sewage purification as well.

Many of the European observations have been made and studied largely with reference to their bearing on geological dynamics, and while of interest from the geological point of view, are less useful for present purposes than those made at the several American Agricultural Experiment Stations.

As an exception to this, Table No. 74, of the results at the Berlin sewage farms in 1884 and 1885, is given.

The mean winter air temperatures at Berlin are: December, 33.5° F.; January, 30°; and February, 31.1°. Soil temperatures have been taken at 14 different points at the depths indicated in Table No. 74. The results here given are the means of all the observations. The deepest frost penetration thus far observed is about 2.5 feet; in ordinary winters the depth of frost does not exceed 1.7 feet.*

* Notes on European Practice in Sewage Disposal. By Chas. H. Swan. Jour. of Assn. of Eng. Socs., vol. vii., No. 7 p. 253 (July, 1888).

TABLE No. 74.—AVERAGE SOIL TEMPERATURES AT THE BERLIN SEWAGE FARMS IN 1884 AND 1885.

(Fahrenheit °.)

Year.	1884.			1885.		
Depth, meters.	0.5 (1.64 ft.)	1 (3.28 ft.)	3 (9.84 ft.)	0.5 (1.64 ft.)	1 (3.28 ft.)	3 (9.84 ft.)
Day of month.						
January 1	40.1	43.3	49.5	40.6	43.4	49.9
January 15	40.1	42.4	48.1	39.1	41.9	49.0
February 1	42.9	43.4	47.5	35.9	39.5	47.7
February 15	43.3	44.7	47.7	38.0	40.6	47.1
March 1	41.1	43 5	47.6	41.1	42.3	46.7
March 15	43.2	43.0	46.8	40.6	42.3	46.7
April 1	44.9	45.3	47.7	43.4	43.7	46.7
April 15	46.8	47.0	47.7	45.3	45.9	47.2
May 1	46.8	46.2	47.9	51.7	52.0	48.1
May 15	56.2	51.7	49.0	50.3	50.5	49.5
June 1	56.7	54.6	51.5	57.8	54.6	50.4
June 15	58.3	55.9	52.2	61.2	58.0	51.8
July 1	60.0	57.5	53.0	64.7	60.8	53.5
July 15	66.0	62.3	54.4	66.5	62.9	55.0
August 1	61.8	61.1	55.9	62.7	61.5	56.2
August 15	64 9	62.5	56.4	62.9	61.8	56.6
September 1	61.4	61.2	57.4	58.0	58.3	56.6
September 15	61.8	60.6	57.3	57.9	57.9	56.4
October 1	60.0	59.7	57.3	55.6	57.0	56.5
October 15	53.1	56.1	56.9	53.0	54.4	55.8
November 1	48.7	51.8	55.5	48.1	50.9	54.5
November 15	46.7	50.0	54.3	45.1	48.2	53.4
December 1	39.5	44.0	52.4	43.1	44.8	51.9
December 15	44.8	45.4	50.8	38.8	42.8	50.7

RELATION OF SPECIFIC HEAT TO SEWAGE DISPOSAL.

The specific heat of a body is defined as the number of heat-units necessary to raise the temperature of one pound of the body 1° F. with water at 32° taken as the unit. In either of its three forms water possesses the greatest specific heat of any substance known, although as ice its specific heat is only one-half that of the liquid form. Notwithstanding the utility of such information in agriculture, comparatively little has been done in the way of determining the specific heat of soils, the following table, No. 75, of relative rates of cooling, from Schübler, embodying about the most useful results thus far obtained.*

* On the Physical Properties of the Soil and on the Means of Investigating them. By Professor Schübler, of the University of Tubingen. Jour. Roy. Ag. Soc. of Eng., vol. i. (1840), pp. 177-218.

The results detailed in this paper of Professor Schübler, while obtained more than 50 years ago, are still the best in many respects to be found anywhere. Recently the South Carolina and Maryland Ag. Ex. Stations have experimented on soil physics, and the following résumé from the Second An. Rept. of the S. Car. Sta. (pp. 76, 77) indicates the nature and extent of the work of this character which it is proposed to carry on at these stations.

Soil Particles: 1. Interpretation of the result of mechanical analysis.

a. Number of particles in unit weight or volume of soil.

b. Diameter of average sized particle of soil and the mean arrangement of the particles.

c. Surface area of particles (this shows the need of still further perfecting the method of mechanical analysis).

2. On a movement of soil particles due to changing water content and changing temperature, as

In obtaining these results a given quantity of dry soil was heated to 145°, and the time required to cool to 70° observed, the temperature of the atmosphere being 61°. The observed times of cooling are stated in the first column; in the second is given the relative power of retaining heat, with lime sand assumed as 100.

In regard to the relative rates of cooling of the several earths as indicated in Table No. 75, it may be remarked that while the relative rate of cooling depends upon the power of retaining heat, it is still not quite identical with specific heat. As stated by Professor Schüb-

related to the growth of roots, and the physical action of manure, with the effect of barometric changes and vapor pressure on the same.

Soil Moisture: 3. Method for the determination of the moisture in the soil by electrical resistance.

4. On the movement of soil moisture.
   a. On the cause and laws of the movement.
   b. On the effect of temperature.
   c. On the effect of manure.
   d. On the effect of rain.
   e. On the effect of cropping and cultivation.
5. Calculation of the relative movement of soil moisture in different soils from the mechanical analysis.
6. Calculation of the relative rate of evaporation and underdrainage from different soils from the mechanical analysis.
7. On the capillary value of different soils from the mechanical analysis.
8. Effect of fineness and compactness on the water-holding power.
9. On the action of underdrains in the soil, and of how they act.
10. On the flocculation and subsidence of clay particles.
11. On the swelling of clay when wet.
12. On the compacting of soils by rain.
13. On the physical action of manures and fertilizers.

Soil Temperature: 14. New form of soil thermometer, which registers the maximum and minimum temperature of a definite layer of soil.

15. The relation of the soil to heat as observed in the field in typical soils or under different conditions of cultivation and fertilization.
16. Calculations of the relation of different soils to heat from the mechanical analyses, with the effect of the water content, cultivation, and cropping.
17. The actual temperature of different soils, with range, etc.
18. Study of the loss of heat from the different soils.
   a. As calculated from the mechanical analysis.
   b. As determined with the radiation thermometer.
19. Specific heat of typical soils.

Meteorology: 20. Temperature of the air and soils, and amount of moisture in same most favorable for plant growth.

   a. Distribution throughout the growing season.
   b. The relative effect on the growth of plants and crop production.
   c. How modified by manure and cultivation.
21. The estimation of the actual amount of moisture in the soils from time to time.
22. Influence of meteorological conditions.
   a. On grain production, as explaining low average yield of grain at the South.
   b. On the distribution of crops throughout the State.
   c. On the growth and ripening of crops.
23. Amount and intensity of sunshine available for the crop.
24. Effect of wind movement on plant growth, especially as to the amount of ammonia supplied to crops.

ler, the rate of cooling does not depend merely upon specific heat, but on the different capacity as well which bodies possess of conducting heat. A body with a low rate of cooling will possess high specific heat and slight conducting power: these two properties combined constitute the power of retaining heat.

TABLE No. 75.

	Time to cool from 145° to 70° F.	Relative power of retaining heat.
Lime sand	3 h. 30 min.	100.0
Quartz sand	3 h. 27 min.	95.6
Clay loam	2 h. 30 min.	71.8
Heavy clay	2 h. 24 min.	68.4
Pure gray clay	2 h. 19 min.	66.7
Garden soil	2 h. 16 min.	64.8
Humus	1 h. 43 min.	49.0
Water	30 h. 7 min.	860.4

Table No. 75 shows that under the stated conditions dry humus will cool about twice as fast as sand, and nearly eighteen times as fast as water, when exposed to the same degree of heat; it also shows, independent of the considerations which have been forcibly presented by the Lawrence experiments, the superior value of sand as a sewage purification medium in winter. In order to illustrate this proposition we will review briefly the *rationale* of the process of applying sewage to an intermittent filtration area from day to day. According to the Lawrence experiments the daily application of sewage disappeared from the surface of coarse mortar-sand in comparatively short periods of time, the actual length depending, as might be expected, largely upon the amount applied. When applied at the rate of 60,000 gallons per acre per day, about 30 minutes usually sufficed for that quantity to sink entirely beneath the surface. At the rate of 100,000 gallons per day per single application, the surface of coarse sand was usually clear in about one hour,* though at times the periods were somewhat longer, as may be seen by inspection of the record in detail. In Table No. 76 a few extracts are given from the original tabulations by way of illustrating the point in question. As the liquid sewage sinks into the sand, thin laminæ of water cover the particles of sand to the extent of about one-ninth of the whole volume, the balance of the space being occupied by sand two-thirds, and air one-fourth. The application of one day is pushed forward by that of the next, the last part of each daily application remaining just below the surface of the sand until the next application is made, when it is in turn pushed forward as before.† Again, it

* For detailed statement as applying to filters of coarse sand and other material, see the tabulations in the Spec. Mass. Bd. of Health Rept., Part II. With very coarse material the daily application frequently disappeared within one minute.

† Spec. Rept., Part II., pp. 6, 7.

TABLE No. 76.—LENGTH OF TIME SEWAGE REMAINED ON SURFACE WHEN APPLIED TO SAND FILTERS (LAWRENCE).

Date.	Tank.	Application per acre, gallons.	Time sewage remained on surface.	Date.	Tank.	Application per acre, gallons.	Time sewage remained on surface.
April 10, 1888.....	No. 1	30,000	0 m.	July 16, 1889......	No. 1	100,000	53 m.
April 24, "	" "	30,000	15 m.	August 10, "	" "	100,000	48 m.
May 4, "	" "	30,000	0 m.	April 1, 1888......	No. 2	30,000	45 m.
August 15, "	" "	60,000	20 m.	April 6, "	" "	30,000	2 h. 18 m.
August 23, "	" "	60,000	18 m.	April 10, "	" "	30,000	1 h.
September 5, "	" "	60,000	20 m.	May 4, "	" "	30,000	48 m.
September 6, "	" "	60,000	42 m.	July 16, "	" "	20,000	1 h. 57 m.
September 7, "	" "	60,000	22 m.	August 14, "	" "	20,000	24 h.
October 16, "	" "	60,000	1 h. 11 m.	August 24, "	" "	20,000	5 h. 41 m.
October 19, "	" "	60,000	1 h. 2 m.	March 11, "	No. 6	30,000	20 m.
December 10, "	" "	60,000	23 m.	March 28, "	" "	30,000	47 m.
December 14, "	" "	60,000	27 m.	April 19, "	" "	30,000	18 m.
January 1, 1889.....	" "	60,000	27 m.	July 12, "	" "	60,000	1 h. 38 m.
January 15, "	" "	60,000	20 m.	August 1, "	" "	60,000	24 h.
February 1, "	" "	60,000	25 m.	December 1, "	" "	60,000	1 h.
February 14, "	" "	60,000	24 m.	January 1, 1889......	" "	60,000	52 m.
March 1, "	" "	60,000	23 m.	February 2, "	" "	60,000	1 h.
March 15, "	" "	60,000	31 m.	April 2, "	" "	60,000	37 m.
April 1, "	" "	60,000	32 m.	June 1, "	" "	60,000	36 m.
April 15, "	" "	60,000	1 h. 51 m.	March 24, 1888......	No. 12	30,000	26 s.
May 1, "	" "	60,000	3 h.	July 27, "	" "	——	24 h.
May 15, "	" "	60,000	9 h. 25 m.	April 5, "	No. 13	60,000	45 s.
June 14, "	" "	60,000	2 h. 18 m.	April 21, "	" "	120,000	1 m. 5 s.
July 2, "	" "	100,000	55 m.				

is clear that a slight circulation of air may be expected to take place through the voids of the sand which are not occupied with liquid, and the cooling effect of winter temperatures will therefore be somewhat greater than when continuous filtration, with its consequent entire exclusion of air, is used. In very cold weather, then, filter areas may be considerably protected from freezing by the use for the time being of continuous filtration rather than intermittent, the high specific heat of the water covering obviously extending greatly the time of reduction to temperature of freezing.

Returning to the specific heat of sand, we may conclude from the preceding that its high capacity for retaining heat will also assist in prolonging the time to freezing. Putting sand in comparison with humus, other things being equal, the time would be doubled before reduction to the temperature of freezing, as shown by Schübler's table.

HOW HEATED BODIES COOL.

The rate at which cooling of various soils and water takes place is thus shown to be of considerable practical importance in sewage disposal; indeed, we may say that a thorough understanding of its laws will assist greatly in reaching a satisfactory solution of the problem of winter purification in cold climates. At present, aside from the experiments of Dulong and Petit and of Peclet, we have little accurate

knowledge of the laws of heat which apply, and what we do derive from their experiments, so far as its application to the present subject is concerned, is far from satisfactory.

The cooling of heated bodies may be effected by either radiation, contact of cold air, or by conduction. In the case of a filter area with a sheet of water covering it, the sources of loss which it is necessary to consider are radiation and contact of cold air. Conduction, aside from the small area of contact of water and soil at the sides, only takes place from the water to the filter area, with the useful result that the heat abstracted from the water by conduction goes to increase the temperature of the filtering material.

Radiation from a given area of surface varies as the temperature. For water its value is 1.085 heat-units per square foot of area per hour for a difference of 1° F. in temperature.

Within limits not exceeding about 30° F. we may say that cooling by contact of air is, for a given area of surface, also proportional to the difference in temperature between the air and the body cooled, in accordance with the law of Newton. For greater differences of temperature the ratio of loss is somewhat higher, as demonstrated by Dulong, but for present purposes the assumption of proportionality of loss to temperature is sufficient. For a difference of 1° F. we may take the loss by cooling from contact with the air, according to Peclet, at 0.595 heat-units per square foot per hour. The combined loss from radiation and contact per square foot per hour for a difference of 1° F. accordingly becomes $(1.085 + 0.595) = 1.680$ heat-units.

In order to illustrate the foregoing let us assume an air temperature of 10° and sewage at a temperature of 45° applied to the depth of four inches on a filter area free of snow. Also assume the time required to completely sink below the surface at one hour. The loss of heat from radiation and contact of cold air per square foot per hour will be approximately $(1.68 \times 35) = 58.8$ heat-units. Four inches in depth gives a volume weight per square foot of 20.8 pounds. The reduction in temperature of the applied sewage before sinking into the filtering material will accordingly be $(58.8 \div 20.8) = 2.8°$ F. To find the time elapsing before reduction under the conditions to the temperature of freezing we have a total loss of heat-units per square foot of $(20.8 \times 13) = 270.4$, of which, as an approximation, we may say 59 heat-units are lost the first hour, 54 the second hour, 50 the third hour, and so on until the whole quantity of 270.4 units is lost in about five and one-half hours. This result is a rapid approximation merely. The subject admits of extended mathematical treatment, but the data are not exact enough to justify the additional expenditure of labor required.*

* The laws of cooling are very complicated, and all formulæ thus far devised are merely approximative. Newton's law asserts that the rate at which a body loses heat is proportional to the dif-

Again, the latent heat of freezing is about 142 units, and the withdrawal of this amount of heat under the conditions assumed, and through the operation of the same law of loss, will still further extend the time of complete congelation. In illustration of this we may consider the case of the stratum of water equivalent to a pound in weight per square foot. Its thickness will be $(12.00 \div 62.4) = 0.192$ inches. The time required for this thickness to congeal will be, under the law of cooling already used, about 3.5 hours. When ice has once formed, however, a somewhat different set of conditions govern. Loss of heat from the water under the ice can then take place only by conduction through the ice cover, and, by reason of the low conductivity of ice, at a lower rate than when the unprotected water was exposed to every passing movement of the air. The weight of water at 32° is somewhat less than at slightly higher temperatures, 39.3° being the temperature of greatest density. Hence cooling by convection will not take place at the low temperatures under consideration. These illustrations, without exhausting the subject, will suffice to indicate why the process of cooling is a prolonged one under the conditions assumed.

The specific heat of ice, however, is, as already stated, only one-half that of water, and hence we may expect a relatively more rapid further reduction of temperature of the ice itself after once actually formed than before; that is to say, ice responds to changes of temperature twice as readily as water.

ference between the temperature of its surface and that of its inclosure. The rate of cooling may be defined as the fall of temperature per unit of time for any given instant considered.

In testing the law of cooling experimentally it is found that if the temperature of a cooling body is observed at equal intervals of time, the excesses above the temperature of the air in which the cooling body is placed form a decreasing series, in which, letting Θ_0 denote the initial excess of temperature, $\frac{1}{m}$ the ratio of the series, we have the excess at the end of one unit of time equal to $\frac{\Theta_0}{m}$, at the end of two units $\frac{\Theta_0}{m^2}$, and after t units $\frac{\Theta_0}{m^t}$. If, then, Θ denote the excess at time, t, there results $\Theta = \frac{\Theta_0}{m^t} = \Theta_0 m^{-t}$.

The following practical expression for the loss of heat by contact with air will answer the requirements of ordinary computation:

$$L = 0.1 F (t-T)^{1.2},$$

in which

L = loss of heat by contact per square foot per hour;

F = factor for movement of air = 4 for quiet air; 5, for moderately moving air; and 6 for rapidly moving air;

t = temperature of heated body; and

T = temperature of the air in contact.

When $(t-T)$ does not exceed about 20° to 30°, we may take $L = 0.1 F (t-T)$.

For ordinary conditions of loss by contact of air with a filter area, F = 5, may be taken.

With great differences of temperature, as for instance 50° to 60°, the neglect of the fractional exponent of $(t-T)$ will lead to relatively larger variations from the actual law than with the smaller differences considered in the foregoing.

In order to insure that winter purification may go on without interruption, the thing to be attained, then, is to prevent the formation of any considerable quantity of ice. As we have seen, the latent heat of freezing is 142 units; when ice is once formed this amount of heat will be required for every pound in the process of melting to water at the temperature of 32°. With sewage at temperature of 45° going on to a frozen filtration area, for every pound of ice converted into water at a temperature of 32° there will be required the reduction of 13 pounds of the onflowing sewage to the same temperature; in other words, with onflowing sewage at temperature of 45° the result of melting one pound of ice will be the reduction of nearly 13 pounds of water to a temperature of 32°. The 13 pounds of water at 32° thus reduced in temperature will, however, still contain their latent heat, amounting to $(13 \times 142) = 1{,}846$ heat units, of which the water must be further entirely deprived before it can all pass into the state of ice.

By way of illustrating the practical significance of the foregoing, let us assume the case of a filtration area covered with water frozen to the depth of three inches; temperature of air, 20°; fresh sewage applied above the ice at a temperature of 45°. We require to know the depth of sewage at this temperature which must be applied in order to melt the three inches of ice. Taking the weight of ice at 58 pounds per cubic foot, we have the weight of a square foot of area three inches thick as 14.5 pounds. The ice is exposed to a temperature of air on one side of 20° and of water on the other at 32°. We may assume its mean temperature at half way between the two, or at 26°.* Under these conditions every pound of ice will require $(142 + 6) = 148$ heat-units in order to reduce it to the liquid state at temperature of 32°, or each square foot of area will require $(14.5 \times 148) = 2{,}146$ heat-units. The amount of water at 45° which will furnish this without beginning to congeal is $(2{,}146 \div 13) = 165$ pounds $= 2.6$ cubic feet; or, what is the same thing, there would be required a depth of water over the area of 2.6 feet. This computation, moreover, has not taken into account the loss of heat of the applied sewage because of cooling from radiation and contact with the air; this of itself would considerably increase the amount necessary to be applied.

The Massachusetts experiments at their very beginning, in the winter of 1887–88, have afforded an excellent practical illustration of the principles now under discussion. For instance, in January, 1888, when sewage was first applied, the mean temperature for the whole month was, as shown in Table No. 69, 15.46°. The sewage was further, for

* This assumption will not be quite true, as the small amount of evaporation which will take place from the exposed surface, even under the extreme conditions assumed, will reduce the mean temperature somewhat lower. It may be considered, nevertheless, near enough for illustrative purposes, which is all that is required here.

reasons already indicated, applied at a temperature only a few degrees above 32°. The result was that some of the filters became frozen, and it was found necessary to heat the sewage by passing a steam coil through the measuring tank. The amount of this heating may be seen by reference to Table No. 70. During February the amount of heating was sufficient to give a mean for the month of 47°, or about 5° above the mean in the sewer. This proving insufficient to free the tank from ice, the sewage was so far warmed artificially in March as to give a mean of about 61° for the whole month. On March 8, sewage at temperature of 57° was applied at the rate of 204,000 gallons per acre, followed by the same quantity on March 9, at temperature of 55°. On March 10, 32,000 gallons per acre was applied at temperature of 69°; March 12 and 13, 40,000 gallons per acre each day at 75°; March 14, 40,000 gallons at 80°; March 15, 50,000 gallons at 68°; and March 16, 50,000 gallons at 70°. From that time to the end of the month the temperature of applied sewage ranged from 68° to 52°; but at no time during that period did the temperature of the effluent rise above 40°. These figures serve to point out saliently the large amount of sensible heat which must have been extracted from the applied sewage before the lost latent heat of the frozen material was fully restored. The mean temperature of the air for the month of March, 1888, was, as shown in Table No. 69, 29.76°.

We may conclude, then, that in case a filtration area becomes frozen solid, the application of sewage at its ordinary water temperature of 45 ° or thereabouts to the exterior of the frozen surface is fundamentally wrong; it will only lead to an increase of the difficulty which it is intended to obviate. In case it is impossible to prevent freezing, the area should be so managed that the daily application of sewage at normal winter temperature may be made to pass under the ice, thereby avoiding the serious loss of heat resulting from contact of water in the liquid state with cold air. A certain amount of loss will still go on through the ice, but, as already shown, less rapidly than from an unprotected water surface. The resulting increase of temperature under the ice will further prevent the penetration of frost into the material of the filter, a point of considerable importance in its bearing upon the quality of the effluent.

By reason of containing a large amount of air entangled among its particles, snow may be considered a poor conductor of heat; it is, therefore, a relatively good covering for a filtration or irrigation area in winter; and the foregoing shows how it may be of practical use if the sewage can be made to run under it, forming a thin layer of ice above.

The preceding discussion enables us to appreciate the real reason why certain soils are warm and others cold. For instance, humus is

usually considered a cold soil by reason of the long time required for it to become warm enough in spring to admit of successful planting. Its capacity for heating to a given temperature is shown by Schübler's table to be double that of sand, and it therefore ought, under the same conditions, to become warm twice as quick. Usually, however, humus is found in valleys, and when without artificial drainage is saturated with water which, from its slowness in absorbing heat, extends the time of warming beyond the better-drained soils of uplands. On the other hand, at the approach of cold weather dry humus will, for the same reason, lose its temperature more quickly than sand, but here again the slowness of the water with which it is saturated to part with its specific heat will extend the time of cooling of the whole, so that in effect it is found that the natural soils of the valleys are generally cooler in summer and warmer in winter than those of the adjacent highlands. This fact will be forcibly brought out in discussing the results of the soil temperature observations at Fort Collins, Colorado, and at Auburn, Alabama.

The cooling effect of evaporation may also be referred to as one of the elements of the problem under discussion. That it is an important element may be appreciated by considering that the evaporation of an inch of water over an acre will require as much heat as can be utilized in warming from the combustion of about eleven tons of coal. In a water-logged soil the evaporation may be expected, therefore, to reduce the summer temperature somewhat below what it would otherwise be. In filtration through coarse sand this loss, while probably slightly more than from a water surface because of the open quality of the material allowing of free circulation of air, can still be endured; if it proceeded at an equally rapid rate in winter it would be a very serious objection, but fortunately the relatively low rate of evaporation in the winter acts to reduce the loss at that time.

Solar and Terrestrial Radiation.

Solar and terrestrial radiation is another branch of the subject not only possessing theoretical interest but practical possibilities in the future of vast significance. In the introduction to his paper, Researches on Solar Heat,* etc., Professor Langley remarks that "the observation of the amount of heat which the sun sends to the earth may be termed the fundamental problem of meteorology." If we knew the original quantity and kind of this heat, how much of it reaches the soil, how it maintains the surface temperature, and how in diminished quantity and altered kind it is finally returned to space,

* Researches on Solar Heat and its Absorption by the Earth's Atmosphere, by Professor S. P. Langley. Professional Papers of the Signal Service, No. xv., 1884.

nearly every element of the problem now under discussion, as well as those pertaining to aërial meteorology, would become predicable.

According to Professor Langley's experiments of 1881 and 1882 it is shown that all the thermal phenomena on which organic life depends hinge upon the atmospheric property of selective absorption, without which the temperature of the soil, even in the tropics, would fall far below zero.

An attempt to define the modern conception of what selective absorption really is would lead too far into the theory of molecular physics, and we may simply say that the paper of Professor Langley furnishes an epitome of all that is at present known in regard to it; a study of the paper will repay any person interested in scientific meteorology and allied subjects.*

In reference to solar radiation it may be stated that the temperature of the air as measured by an ordinary thermometer does not indicate the real intensity of the sun's heat. Such a thermometer really measures only the amount of heat absorbed by the air; even when exposed to the direct rays of the sun its indications are below the real solar intensity by reason of the cooling effect of moving currents of air. In order to avoid the effect of such currents the vacuum solar radiation thermometer, which consists of a blackened bulb radiation thermometer inclosed in a glass tube and globe from which all air has been exhausted, is used; its indications are from 20° to 30° higher than those from a similar instrument with the bulb freely exposed to the moving air. By its use it is found that the solar intensity varies greatly at different places without reference to the temperature of the air. The intensity of solar radiation at any given place is indicated by comparing the solar radiation readings with the maximum air temperature.

Again it has been known for a long time that the radiation of heat from the surface of the earth during the night reduces the temperature of the surface below that of the surrounding air. The amount of this radiation, or rather the reduction of temperature resulting therefrom, is shown approximately by comparing the readings of a terrestrial radiation thermometer with those of a minimum air thermometer. Some of the results obtained at a few points in this country have been tabulated in connection with the soil temperature observations following.

Thus far we have considered the relative heating capacity of the soil without reference to its color, although it is obvious from the difference in effect of solar heat on a blackened thermometer bulb that the effect of color is of considerable importance; and while in saturated soils the relatively high specific heat of water is, as we have seen, the

* Deschanel's Natural Philosophy (Everett's Translation) may also be referred to for clear elementary definition of selective emission and absorption.

controlling factor, nevertheless the influence of color as assisting selective absorption may still justly claim momentary attention.

The fact that dark-colored soils are more easily warmed by the sun's rays than light ones has been frequently observed; and experimental proof that an elevation of several degrees in the temperature of a light-colored soil may be caused by strewing its surface with charcoal powder or black vegetable mould has been obtained. Observations on this point have been made by several European investigators, but in the absence of explicit statements in regard to the effect of the entrained moisture of the soil the results have relative value only.*

The best results are again those of Schübler, who observed the temperature of various dry soils when exposed to solar heat with their surfaces either blackened by a thin coating of lampblack or whitened by powdered magnesia. Schübler also determined the relative temperatures of various soils, both dry and wet, with surfaces in natural condition. Some of the results of these two determinations are embodied in Table No. 77.

TABLE No. 77.—HEATING EFFECT OF THE SUN ON WET AND DRY SOILS OF DIFFERENT COLORS.

(Fahrenheit °.)

Material.	Mean of the highest temperature of the upper surfaces of:					
	Dry earth.		Difference.	Natural color.		Difference.
	Whitened.	Blackened.		Wet.	Dry.	
Magnesia, pure white	108.7	121.3	12.6	95.2	108.7	13.5
Fine carbonate of lime, white	109.2	122.9	13.7	96.1	109.4	13.3
Gypsum, bright white-gray	110.3	124.3	14.0	97.3	110.5	13.2
Plough-land, gray	107.6	122.0	14.4	97.7	111.7	14.0
Sandy clay, yellowish	108.3	121.6	13.3	98.2	111.4	13.2
Quartz-sand, bright yellowish-gray	109.9	123.6	13.7	99.1	112.6	13.5
Loam, yellowish	107.8	121.1	13.3	99.1	112.1	13.0
Lime-sand, whitish-gray	109.9	124.0	14.1	99.3	112.1	12.8
Heavy clay soil, yellowish-gray	107.4	120.4	13.0	99.3	112.3	13.0
Pure clay, bluish-gray	106.3	120.0	13.7	99.5	113.0	13.5
Garden mould, blackish-gray	108.3	122.5	14.2	99.5	113.5	14.0
Slaty marl, brownish-red	108.3	123.4	15.1	101.8	115.3	13.5
Humus, brownish-black	108.5	120.9	12.4	103.6	117.3	13.7

Studying this table we note: (1) That the lampblack surface was warmed on an average about 13.5° more than the white; (2) that the character of the surface determined the temperature. The results show that for all the soils the temperatures with either lampblack or magnesia were essentially the same.

In the second series with natural surface, and either wet or dry, we

* For résumé of results in this direction see, (1) Storer's Agriculture, vol. i., pp. 112–116; (2) Johnson's How Plants Grow, pp. 186–199.

note for gray soil wet, a temperature of 97.7° ; and for brownish-black humus wet, 103.6°, giving a range of 5.9°. The same soils dry give, for gray soil, 111.7°, and for humus, 117.3°, a range of 5.6°.

Again the difference in favor of the dry soils as against the wet is about 13.5°, the same as observed for the soils with whitened and blackened surfaces.

Further we observe : (1) That all the soils when wet uniformly present a lower temperature than when dry and whitened ; (2) that the dark-colored soils when wet were warmer than the wet light-colored ones. Again comparing the two sets of results it is evident that the deepening of the color has in all the wet soils materially assisted the temperature, which rises in a clear relation to the deepening of the color until in the case of brownish-black humus it lacks only 3.6° of being as high as the same soil dry with lampblack surface.

Among earths and rocks specific heat seems to vary in some degree in proportion to density; and as a mean value we may say that gravel stone in comparison with water taken as unity has a specific heat of about 0.20. The upper surface of a filter area composed of fine dark-colored gravel will therefore possess greater efficiency than one not so covered; for such covering the rounded slate-colored pebbles of many river-beds will answer admirably.

Again the specific heat of wood charcoal is 0.24, and its use for surfacing a filter can be considered, on account of its black color, of possible utility.

Further, on the subject of increasing the temperature of the soil of filter areas, it may be stated that the nitrifying process itself is, when active, no inconsiderable source of heat, which is liberated by chemical action from the organic substances in process of disintegration.

In regard to increasing the temperature of filter areas by the use of dark-colored surfaces it may appear at first sight that, inasmuch as radiation or absorption are apparently converse operations, the net result for a complete cycle will be the same as though the surface had been left in its natural condition. The principle of selective absorption, however, shows us that the rays of low intensity of wave-motion may be almost completely absorbed. Again radiation is not in every sense the converse of absorption, the quality of the surface has more to do with its quantity than color, as may be proven by suspending two terrestrial radiation thermometers at the same height, one above sod and the other above sand, when it will be found that the one above sod will show the lower temperature. Moreover bodies differ in their power of absorbing and radiating heat of different degrees of intensity of wave-motion. If black cloth or black paper be spread on snow on which the sun is shining the snow will melt more rapidly under the cloth than elsewhere. If the cloth is suspended above the snow the

melting still goes on the same as when resting upon it. The reasons for this are: (1) That snow has a special capacity for heat of low intensity; (2) the effect of absorption, conduction, and radiation by the black cloth is to transform the solar rays from a state of high intensity to that of low intensity, in which state they are capable of doing their maximum work in restoring the lost latent heat of snow. Expressing the fact in another way we may imagine that the effect of the black cloth has been to so reduce the intensity of wave-motion as to bring solar heat to a state wherein it can act the most effectively upon snow, a substance which is only exceeded by water in the slowness with which it receives and parts with heat. We may conclude then that the selecting of a material for the surface of a filter of such absorbing and radiating capacity as to utilize to some extent the heat gained during the day in maintaining the temperature during the night is quite within the possibilities of our present knowledge of heat.

American Soil Temperature Observations.

We may now take up the consideration of a few of the soil temperature observations which have been kept by a number of the Agricultural Experiment Stations for the last few years.

The soil thermometer in common use in this country was devised for the New York State Station at Geneva, by Henry J. Green, in 1882. So far as known to the author, with the exception of a short series made by Dr. Kedzie of the Michigan State Agricultural College a few years previously, the Geneva observations were the first extended series begun in this country. Unfortunately they have been confined entirely to the growing season from April to October, inclusive, and are without value for the present purpose. The station is to be credited, however, with the first systematic beginning of such work.

The thermometers devised by Mr. Green are a series of ordinary mercurial thermometers with sufficient length of stem to project above the ground for any depth. The graduation is far enough above the surface to enable the thermometer to be read by the observer when kneeling. They are encased in well-seasoned wood except at the bottom of the bulb and at the graduation. At the sides of the bulb, holes are bored through the wood to admit of more perfect contact with the soil. In setting the thermometer a trench is excavated, a groove cut at the side, the thermometers planted therein at the proper depths and the trench refilled as nearly as possible to its natural condition. The errors of soil thermometers may be determined by comparison with a standard and corrections applied to the observations the same as to any other mercurial thermometer.

In Table No. 78 is given the mean soil temperatures and the snowfall

TABLE NO. 78.—MAXIMUM, MINIMUM, AND MEAN TEMPERATURES OF THE AIR AND THE SAME FOR THE SOIL AT VARIOUS DEPTHS, FOR THE MONTHS FROM NOVEMBER, 1890, TO APRIL, 1891, INCLUSIVE, AT STATE COLLEGE, PENNSYLVANIA.

(Fahrenheit °.)

Month.	Air 15 feet above ground.			Soil, depth of 3 inches.			Soil, depth of 6 inches.			Soil, depth of 1 foot.			Soil, depth of 2 feet.			Snowfall, inches.
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	
1890.																
Nov....	66.0	17.0	41.2	49.5	33.5	40.9	50.0	35.0	41.7	48.5	37.5	43.2	48.0	40.5	45.4	0.6
Dec....	47.0	1.0	25.6	34.0	32.0	32.8	34.5	33.0	33.6	37.5	34.5	35.4	40.5	36.5	37.9	32.6
1891.																
Jan....	49.0	1.0	28.9	32.5	23.0	30.6	33.0	27.0	31.4	34.5	33.0	33.3	35.0	34.5	35.0	13.8
Feb. ...	58.0	4.0	33.1	45.0	23.5	32.4	41.5	27.5	32.3	37.5	33.0	33.6	36.5	34.0	34.4	40.5
March..	54.0	0.0	31.6	41.5	24.0	32.7	40.5	30.0	33.5	39.5	33.0	34.4	38.0	34.0	35.1	15.1
April...	82.0	20.0	49.5	62.0	31.5	45.9	56.5	33.0	46.0	55.0	35.0	45.1	50.5	36.5	43.1	0.5

in comparison with the mean air temperature for the winter of 1890–91, as kept at State College, Pennsylvania in latitude, 40° 55′ north, longitude 77° 51′ west. Observations have been made during the growing season for several years, but the foregoing are the first winter records kept. The station is 1,200 feet above tide-water. The soil in which the thermometers stand is a moderately dark, compact loam for a depth of about seven inches and after that a stiff clay subsoil. The surface immediately over the thermometers is free from vegetation and during the summer kept loose by stirring from time to time. The most interesting point in connection with this series is the slight frost penetration in December, 1890, when the minimum temperature for the month was 1.0°, with a mean of 25.6°, the snowfall for the month being 32.6 inches.

At the Maine State College, Orono, Maine, in latitude 44° 54′ north, and longitude 68° 40′ west, a series of soil temperature readings have been kept for the growing season of the last three years. Table No. 79 gives the results for 1889.

Terrestrial and solar radiation readings are also given and herewith included by way of illustrating the relation of this class of data to soil temperatures. The terrestrial radiation thermometer was placed over grass and within six inches of the surface of the ground, while the minimum air thermometer with which it is compared was four feet from the ground. The greatest range of the terrestrial radiation thermometer from the minimum air was 10.8°. The quality of the soil in which the soil thermometers are placed and the elevation of the station above tide-water are not stated in the reports at hand.

The mean winter temperatures of air at Orono in 1889 were: November, 38.9°; December, 27.6°; January, 25.0°; February, 15.2°; March, 32.9°; April, 45.1°. The minimum winter temperature was — 20.0°, in March. The snowfall was: November, 6 inches; December, 6.5 in-

TABLE No. 79.—MEAN TEMPERATURE OF THE AIR, TERRESTRIAL RADIATION, SOLAR RADIATION, AND MEAN SOIL TEMPERATURES AT VARIOUS DEPTHS FOR THE MONTHS FROM MAY TO OCTOBER, 1889, INCLUSIVE, AT MAINE STATE COLLEGE, ORONO, MAINE.

(Fahrenheit °.)

Month.	Air.				Terrestrial radiation.			Solar radiation.			Soil, depth of 3 inches.			
	7 A. M.	1 P. M.	7 P. M.	Mean.	Mean of minimum temperature.	Mean of ter. rad. ther.	Loss by radiation.	Mean of sun thermometer.	Mean of maximum temperature.	Excess of solar intensity.	7 A. M.	1 P. M.	7 P. M.	Mean.
1889.														
May.......	52.95	68.30	59.47	60.24	46.63	38.48	8.15	133.02	67.85	65.17	51.50	60.33	59.70	57.18
June......	63.36	74.27	68.07	68.57	53.25	49.20	4.05	134.22	73.45	60.77	61.38	69.62	67.76	66.25
July.......	65.12	75.75	70.86	70.58	55.08	50.59	4.49	139.55	75.30	64.25	63.10	70.86	69.54	67.83
August....	59.97	74.20	66.81	66.99	53.05	47.66	5.39	137.56	73.72	63.84	61.75	68.91	68.01	66.22
September.	54.39	70.86	61.55	62.27	49.07	44.60	4.47	122.79	71.23	51.56	57.74	63.01	62.89	61.21
October ...	37.41	52.80	44.05	44.75	33.91	28.48	5.43	105.86	52.78	53.08	43.80	47.31	46.72	45.94
Means...	55.53	69.36	61.80	62.23	48.50	43.17	5.33	128.83	69.05	59.78	56.54	63.34	62.44	60.77

Month.	Soil at depth of 1 foot.				Soil, depth of 2 feet.				Soil, depth of 3 feet.			
	7 A.M.	1 P.M.	7 P.M.	Mean.	7 A.M.	1 P.M.	7 P.M.	Mean.	7 A.M.	1 P.M.	7 P.M.	Mean.
1889.												
May.....................	52.46	52.15	53.21	52.61	48.84	49.06	49.01	48.96	46.28	46.42	46.48	46.39
June.....................	61.26	61.10	61.79	61.38	57.23	57.43	57.41	57.36	54.36	54.54	54.52	54.47
July.....................	64.30	64.02	64.29	64.20	60.99	61.14	61.03	61.05	58.50	58.57	58.57	58.56
August...................	63.31	63.10	63.31	63.24	60.96	61.10	60.97	61.01	59.16	59.23	59.23	59.23
September...............	60.30	60.21	60.04	60.18	59.42	59.51	59.36	59.43	58.40	58.37	58.37	58.43
October..................	48.17	47.83	47.85	47.95	50.63	50.65	50.54	50.61	51.66	51.61	51.61	51.64
Means...................	58.30	58.06	58.41	58.26	56.34	56.48	56.39	56.40	54.73	54.79	54.79	54.79

ches; January, 15.5 inches; February, 28.3 inches; March, 4 inches; April, 4 inches.

In Table No. 80 we have the means of a series of observations of temperature of air and soil as taken at 2 P. M., the approximate time of maximum daily temperature of each day for the months of January to April inclusive, 1889, at St. Anthony Park, Minnesota. The severity of the Minnesota climate will be appreciated when it is remarked that the mean of 2 P. M. observations for February was 17°. The winter of 1888–89 is stated, however, to have been on the whole a mild one. Nevertheless the soil of the Minnesota Station, which is gravel and sand with an admixture of clay, froze to a depth of between four and five feet; the greatest penetration of frost took place in the month of March, when the mean air temperature was 44° and the upper layers of soil had entirely lost their frost to a depth of 12 inches. The temperature at depth of five feet read 32° on three days in that month, 33° being the lowest in February, that temperature only being reached for the first time on February 22. On February 1 the temperature at five feet was

TABLE NO. 80.—APPROXIMATE MAXIMUM, MINIMUM, AND MEAN TEMPERATURE OF THE AIR AND THE SAME FOR THE SOIL AT VARIOUS DEPTHS, FOR THE MONTHS FROM JANUARY TO APRIL, 1889, INCLUSIVE, AT ST. ANTHONY PARK, MINNESOTA. *

(Fahrenheit.°)

Month.	Air 5 feet above ground.			Depth of 3 inches.			Depth of 1 foot.			Depth of 2 feet.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1889.												
January	38	10	25	33	15	25	30	18	25	31	24	29
February	46	—3	17	32	6	19	27	18	22	28	18	24
March	62	14	44	59	21	41	39	26	32	32	25	30
April	68	42	56	66	46	58	50	35	43	45	32	39

Month.	Depth of 3 feet.			Depth of 4 feet.			Depth of 5 feet.			Depth of 6 feet.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1889.												
January	35	31	33	38	34	36	40	36	38	41	37	39
February	31	25	29	34	30	32	36	33	34	37	34	36
March	32	26	30	32	30	31	33	32	33	34	34	34
April	43	32	37	41	32	36	40	33	36	34	39	36

* The results in this table are all based upon the 2 P.M. daily observations. The maximum and minimum are the highest and lowest observations for each month.

36°; it gradually fell until 33° was reached on the 22d, as just stated. At the depth of six feet the temperature ranged from 37° to 34° in February and remained stationary at 34° for the whole of March and until April 14, when the temperature advanced to 35°. From that time to the end of the month the tendency was slowly upward at six feet, reaching 39° at the end of the month.

In reference to snow protection at St. Anthony Park, it is stated that the surface about the soil thermometers was nearly bare and fully exposed to the northwest winds, which are the coldest of the locality.

These Minnesota observations are of special interest as illustrating the length of time required for the ground to free itself from frost when once frozen. The mean air temperature for March was 44°, with a mean soil temperature at the depth of three inches of 41°. At the depth of two feet the temperature of 32° was not attained until March 28 and remained at that point until April 5. These results show the considerable length of time required for the soil and entrained moisture to recover its lost latent heat. In winters of extreme cold the soil of Minnesota is said to freeze to the depth of six feet. Experimental verification of this by the use of thermometers is lacking, as these observations have not been carried on since the winter of 1888-89.

In Table No. 81 we have the results of air and soil temperature observations at Lincoln, Nebraska (latitude 40°50′ north, longitude 96°45′ west), for the winter of 1890–91, and the months of November and December, 1891. The station is about 1,150 feet above tide-water and subject to a snowfall at times of over two feet. The soil is described as a fine black loam from 14 to 18 inches deep, underlaid by a bed of yellow clay. Table No. 81 is of special interest by reason of

TABLE No. 81.—MAXIMUM, MINIMUM, AND MEAN TEMPERATURE OF AIR AND SOIL FOR THE MONTHS INDICATED, AT LINCOLN, NEBRASKA.

(Fahrenheit °.)

Month.	Air.			Soil, depth of 3 inches.			Soil, depth of 1 foot.			Soil, depth of 2 feet.			Soil, depth of 3 feet.			Snowfall in inches.
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	
1890.																
November...	66.0	20	38.9	57.5	32.0	37.5	52.5	40.0	44.6	53.7	45.0	49.4	55.5	48.0	51.5	....
December...	59.5	5	30.9	41.0	23.0	32.1	41.5	34.0	36.1	45.0	39.0	41.0	48.0	41.7	44.2	3.2
1891.																
January.....	....	....	27.9	35.1	22.7	29.4	36.5	31.4	33.0	39.2	35.7	37.1	41.6	38.5	39.8	....
February....	....	....	20.1	31.7	14.6	24.5	32.6	24.2	28.8	35.9	31.4	33.5	38.4	34.8	35.4	13.0
March.......	....	....	28.4	41.6	16.4	30.7	36.9	22.8	30.3	35.9	30.0	32 0	36.4	33.2	34.4	18.8
April........	....	....	53.4	69.6	33.7	53.6	60.9	35.7	48.6	54.3	36.2	44.5	50.6	36.5	42.4	....
November...	78.0	3	34 5	52.6	26.3	36.6	51.0	37.3	43.4	53.8	42.8	47.7	55.2	46.0	50.7	0.1
December....	64.5	−1	32.6	44.9	29.2	33.9	42.3	35.0	37.6	43.3	39.0	41.1	45 9	42.0	43.8	0.4

exhibiting the slight frost penetration in the month of February, 1891, when the mean air temperature was 20.1° ; and by way of illustration we will consider the meteorology of that and the following month a little in detail. The preceding month of January had a mean air temperature of 27.9° and a total precipitation of 1.58 inch, all in the form of rain. The ground was in consequence unprotected during the whole of January, which resulted in frost penetration to a depth of 12 inches on the 17th, when the reading at 12 inches was 31.5°. At the depth of 9 inches a reading of 31.6° was reached on the 13th. On January 31, the reading at 6 inches was 32.1° ; at 9 inches, 32.1° ; at 12 inches, 32.9° ; at 2 feet, 36° ; and at 3 feet, 38.5°. Except the first 6 inches in depth the ground was entirely clear of frost on that date. The mean temperature of the air on January 30 was 32.3° ; on the 31st, 15.3° ; on February 1 it was − 2.2° ; while on February 2 it was 0.2°. On February 3 the soil temperature at depth of 3 inches was 14.6° ; at 6 inches, 17.7° ; at 9 inches, 24° ; at 12 inches, 25.6° ; and at 24 inches, 35.3°. Several inches of snowfall occurred on the 8th with a mean air temperature of 16°. From the 8th to the 19th, when an additional snowfall occurred, mean air temperatures ranged from 57° on the 9th, to 45° on the 14th ; to 14° on the 16th and 17th, and 27° on the 19th. On the 14th the soil temperatures at

various depths were: 3 inches, 30.5°; 6 inches, 29.9°; 9 inches, 31.6°; 12 inches, 30.6°; at 2 feet, 33.4°; and at 3 feet, 36°. Another fall of snow of a few inches occurred on the 27th, with a mean temperature of the air for that day of 8.7°. On February 28 the mean air temperature was 3.3°, with soil temperatures for the same date as follows: at 3 inches, 16.3°; at 6 inches, 19.2°; at 9 inches, 23.8°; at 12 inches, 24.2°; at 2 feet, 31.4°; and at 3 feet, 34.8°. In March the daily mean temperature ran below 32° every day except one until the 15th, when it rose to 38°, the exception in the previous part of the month being 34° on the 10th. From the 15th to the end of the month the mean daily air temperature was above 32° for every day except the 18th and 26th, when 29° and 31° were respectively reached. Heavy snowfalls occurred on the 6th and 7th, the total for the month, the most of which fell on these two days, being 18.8 inches. The soil temperatures in March were: On the 14th, at a depth of three inches, 24.7°; at 12 inches, 29.8°; at 2 feet, 31.4°; and at 3 feet, 33.7. With the great rise in air temperature which began on the 15th the ground cleared itself of frost at various depths as follows: The temperature at 3 inches was 37.7° on the 16th; at 6 inches it was 32.3° on the 20th; at 9 inches, 32.1° on the 23d; at 12 inches, 32.1° on the 23d, at 2 feet, 32.1 on the 17th; the minimum temperature at that depth having occurred on March 5 and 6, with readings at 30°. At the depth of 3 feet the minimum soil temperature of the winter was 33.2° on March 9. On March 31 the soil temperatures at various depths were; at 3 inches, 41.6°; at 6 inches, 40.3°; at 9 inches, 37.8°; at 12 inches, 36.9°; at 2 feet 35.9°; at 3 feet, 36.4°.

In April, with a mean air temperature of 53.4°, the soil temperatures rose rapidly, attaining on the 30th, at a depth of 3 inches, 66.1°; at 12 inches, 60.9°; at 2 feet, 54.3°; at 3 feet, 50.6°.

The mean air temperature of May, 1891, was 60°, with soil temperatures on the 31st of, at the depth of 3 inches, 77.3°; at 12 inches, 67.9°; at 2 feet, 59.9°; and at 3 feet, 56°.

The Nebraska observations contrast strongly with those in Minnesota, showing how much quicker the fine black soil of the Nebraska prairie cleared itself of frost than did the less responsive material at the Minnesota Station. Again they are of interest in comparison with the results at the Colorado station, in nearly the same latitude, where on account of high altitude entirely different meteorological conditions obtain.

The most elaborate set of observations of terrestrial meteorology thus far made by any of the Agricultural Experiment Stations are those of the Colorado Station at Fort Collins. Tables Nos. 82 to 87 show some of the results as compiled from data given in the Annual Reports of the station. The observations at Fort Collins are of considerable

TABLE NO. 82.—MAXIMUM, MINIMUM, AND MEAN TEMPERATURE OF THE AIR FOR THE MONTHS JANUARY TO APRIL, INCLUSIVE, 1889 AND 1890, AT FORT COLLINS, COLORADO.

(Fahrenheit °.)

Month.	1889.			1890.		
	Max.	Min.	Mean.	Max.	Min.	Mean.
January	58.0	— 3.5	22.0	65.6	— 13.0	20.8
February	62.0	— 16.0	25.6	68.3	— 20.0	24.9
March	67.8	17.0	41.6	70.1	— 9.0	36.0
April	79.0	24.0	50.6	78 0	13.8	45.2

TABLE NO. 83.—WEEKLY MEANS OF SOIL TEMPERATURES AT THE DEPTHS INDICATED FROM JANUARY TO MAY FOR THE YEARS 1889 AND 1890, AT FORT COLLINS, COLORADO.

(Fahrenheit °.)

Week ending.	1889.						Week ending.	1890.					
	3 in.	6 in.	1 ft.	2 ft.	3 ft.	6 ft.		3 in.	6 in.	1 ft.	2 ft.	3 ft.	6 ft.
January 5	21.3	23.4	27.6	33.6	37.0	44.2	January 4	28.7	31.1	33 5	36.3	38.6	44.3
January 12	24.5	25.5	27.7	32.4	35.6	43.2	January 11	27.5	29.5	31.5	34.4	37.0	43.5
January 19	24.8	25.9	28.2	32.2	35.1	42.4	January 18	25.6	27.2	30.0	33.4	35.9	42.6
January 26	22.0	23.2	26.2	31.4	34.4	41.7	January 25	25.8	27.1	28.8	32.4	34.9	41.7
February 2	26.0	26.7	27.9	31.1	33.9	41.0	February 1	32.7	32.2	31.5	32.4	34.5	41.0
February 9	30.2	29.9	30.2	31.5	33.9	40.5	February 8	35.0	34.4	32.6	33.2	34.8	40.6
February 16	32.9	32.1	31.1	32.2	34.3	40.2	February 15	31.5	32.5	33.3	34.6	35.9	40.5
February 23	25.4	27.3	30.0	32.8	34.8	40.2	February 22	34.7	35.8	35.1	35.6	36.5	40.6
March 2	31.3	30.4	30.2	32.3	34.3	40.1	March 1	29.0	31.2	33.3	35.2	26.7	40.7
March 9	39.4	37.6	35.6	34.7	35.6	39.9	March 8	33.2	32 5	32.2	34.1	35.8	40.5
March 16	42.1	40.8	39.6	39.3	38.7	40.5	March 15	34.4	35 3	35.3	35.8	26.7	40.3
March 23	44.9	44.3	43.0	41.5	41.2	41.4	March 22	44.1	44.1	41.9	39.5	38.7	40.7
March 30	46.1	45.7	44.2	43.0	42.7	42.3	March 29	45.1	46.0	45.1	43.3	42.2	41.9
April 6	53.9	53.0	49.8	46.8	45.3	43.5	April 5	43.5	44.2	43.6	43.0	42.8	43.1
April 13	48.5	49.0	48.2	47.5	46.9	44.7	April 12	51.2	51.4	49.6	46.8	45.0	44.0
April 20	53.6	53.2	51.1	49.7	48.1	45.7	April 19	46.2	47.1	47.2	46.7	46.2	45.2
April 27	59.4	58.5	55.0	51.7	49.9	46.9	April 26	47.6	48.3	48.7	47.8	47.0	45.8
May 4	51.7	52.9	51.8	51.7	51.0	48.0	May 3	53.3	53.3	51.9	49.3	47.9	46.6

TABLE NO. 84.—MAXIMUM, MINIMUM, AND MEAN TEMPERATURES OF AIR; MEAN OF TERRESTRIAL RADIATION OBSERVATIONS AND MEAN SOIL TEMPERATURES FOR 1890, AT FORT COLLINS, COLORADO.

(Fahrenheit. °)

Month.	Air 6 feet above ground.				Mean terrestrial radiation.			Mean soil temperatures, depth of:						Snowfall, inches.
	Mean of 7 A.M. and 7 P.M.	Mean, max.	Mean of max. and min.	Mean, min.	6 inches.	1 foot.	2 feet.	3 inches.	6 inches.	1 foot.	2 feet.	3 feet.	6 feet.	
1890.														
January	20.8	39.8	24.7	9.6	4.4	....	....	28.0	29.4	31.1	33.8	36.2	42.0	2.1
February	24.9	45.0	30.0	15.0	9.9	10.8	11.4	32.5	33.3	33.6	34.6	36.0	46.0	2.3
March	36.0	52.9	38.0	23.2	18.4	19.9	19.7	39.2	39.5	38.6	38.2	38.3	40.8	2.7
April	45.2	60.0	46.5	33.1	29.2	30.3	30.4	47.1	47.7	47.3	46.1	45.2	44.6	4.5
May	55.4	71.2	58.0	41.0	33.8	36.9	37.7	57.6	57.5	55.9	52.9	51.0	48 6	0.8
June	63.5	81.2	64.0	46.8	37.3	40.9	41.8	69.3	68.1	65.5	60.6	58.0	53.2	....
July	69.9	87.1	71.1	55.2	46.2	51.1	51.6	74.3	73.8	71.0	67.3	64.7	58.8	....
August	63.7	80.9	66.1	51.2	41.5	47.6	48.0	66.7	67.2	67.0	65.9	64.9	61.7	...
September	56.0	77.0	58.3	39.6	....	35.2	36.2	57.6	58.7	60.2	61.2	61.7	62.0	....
October	41.8	63.8	47.4	31.0	....	26.3	27.0	47.0	48.4	50.5	53.0	54.6	57 7	....
November	30.8	54.9	38.1	21.3	12.8	16.4	17.3	36.7	38.2	40.8	44.2	46.7	52.1	3.2
December	27.2	49.6	37.8	18.3	8.4	14.9	16.2	32.1	33.3	35.5	38.0	40.5	46.7	2.2

? 34.0

interest by reason of the unusual location of the station at an elevation of about 4,980 feet above tide (latitude 40°35′ north, longitude 105°0′ west). The mean air temperatures, January to April inclusive, for the two years 1888 and 1890 are shown in Table No. 82. The weekly mean soil temperature for the same months and years have been tabulated in Table No. 83, the record here used being from a set of thermometers placed in loam which sometimes receives artificial moisture from the overflow of an adjacent irrigated area. The rainfall at this station is slight, the record showing a mean of 13.58 inches annually. The larger part of this occurs in the spring and summer months. The winter months are stated to be almost entirely free from storms of every character, what little precipitation there is being in the form of snow and lasting only a short time. The average of stormy days in winter for several years has been for December, 1.3 days ; for January, 3.6 days; and February, 3.6 days. The winter days are mostly clear with a relatively intense solar radiation. The mean total percentages, six months of the year, compared with Central New York, are as follows:

	January.	February.	March.	April.	November.	December.
Fort Collins, Colorado	72	67	70	57	66	66
Central New York	17	25	29	39	25	21
Difference	55	42	41	18	41	45

The solar radiation at Fort Collins is high and generally speaking probably in excess of the terrestrial radiation. The observations, however, are still in the experimental stage and this conclusion can be

TABLE No. 85 —DIFFERENCES IN TEMPERATURE OF THE SOIL AT VARIOUS DEPTHS IN DRY AND WET GROUND AT FORT COLLINS, COLORADO, IN THE MONTHS INDICATED, IN 1890.

(Fahrenheit.°)

Weekly readings, 1890.	Set B., wet ground, depth :				Set C., dry ground, depth :			
	6 in.	1 ft.	2 ft.	3 ft.	6 in.	1 ft.	2 ft.	3 ft.
July 3	72.1	68.1	63.4	61.1	78 4	73.6	70.0	65.4
July 10	73.3	69.4	64.4	61.9	77.2	74.8	70.5	62.1
July 17	72.2	70.9	66.0	63.9	76.3	76.6	72.6	57.8
July 24	74.6	70.7	66.2	64.2	80.7	76.0	72.1	68.3
July 31	73.4	68.7	65.9	64.4	76.8	72.7	71.4	68.5
August 7	74.1	70.4	66.6	64.7	78.6	75.2	71.9	68.3
August 14	69.6	67.7	65.6	64.5	71.2	70.5	69.8	67.8
August 22	69.1	65.3	63.5	62.8	68.7	67.1	66.3	65.2
August 28	69.6	66.2	63.8	63.0	70.7	68 0	66.7	64.8
September 4	68.9	65.1	63.8	63.2	69.7	67.1	66.7	64.8
Means	**71.7**	**68.2**	**64.9**	**63.4**	**74.8**	**72.2**	**69.8**	**65.3**
November 7	50.1	46.6	49.6	51 4	43.7	46.1	50.9	51.2
November 21	39.6	40.9	43.7	46.4	38.9	39.4	43.4	45.4
November 28	25.1	39.9	42.9	45.3	35.4	39.4	42.3	44.7
December 4	47.8	39.8	42.4	44.6	37.0	37.9	41.8	43.9
December 20	33.3	35.3	38.7	41.5	31.4	33.0	37.4	40.2
December 26	35.0	35.3	38.0	40.7	34.2	33.3	34.4	39.2
1891.								
January 2	31.7	35.3	38.0	40.7	31.1	33.1	37.4	39.1
Means	**37.5**	**39.0**	**41.9**	**44.4**	**35.9**	**37.5**	**41.1**	**43.4**

TABLE No. 86.—MONTHLY EVAPORATION AT FORT COLLINS, COLORADO, FROM 1887 TO 1890, INCLUSIVE.

(Inches.)

Year.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1887	....	....	4.60	5.55	5.19	5.75	5.23	4.24	4.12	3.26	1.48	1.60	....
1888	....	....	....	....	4.45	7.70	7.00	4.06	3.94	2.17	1.35	0.99	....
1889	1.08	1.03	2.75	4.06	3.72	4.34	5.20	5.15	5.19	3.28	0.62	1.42	37.83
1890	0.86	2.36	3.48	3.50	4.32	5.71	5.44	5.76	3.69	2.71	1.32	1.10	40.24
Means	**0.97**	**1.69**	**3.61**	**4.37**	**4.42**	**5.87**	**5.72**	**4.80**	**4.23**	**2.85**	**1.19**	**1.28**	....

TABLE No. 87.—SOLAR AND TERRESTRIAL RADIATION AT FORT COLLINS, COLORADO.

(Fahrenheit °.)

Month.	Day.	Thermometer.				Month.	Day.	Thermometer.			
		Maximum.	Minimum.	Solar rad.	Ter. rad.			Maximum.	Minimum.	Solar rad.	Ter. rad.
1888.						1888.					
January	1	40	10	33	12	April	3	71	30	44	12
"	7	13	−15	45	11	"	5	66	46	73	18
"	8	15	−12	48	9	"	11	63	30	62	8
"	15	2	−28	60	7	"	12	80	30	57	16
"	16	7	−17	65	8	"	22	87	48	20	24
February	20	50	21	68	11	November	2	64	29	57	9
"	27	65	25	60	21	"	6	40	32	67	22
"	28	67	30	60	11	"	20	53	13	55	5
"	29	40	25	8	9	"	26	49	26	70	8
March	3	28	9	87	14	December	4	68	26	54	11
"	4	26	4	88	4	"	20	57	22	59.1	15.5
"	5	30	3	76	11	"	27	31	4	81	13.5
						"	28	41	-4	55	11

considered as tentative only. If it turns out to be true on further study it may be considered as possibly explaining the relatively high temperature of the soils in winter. Thus far trouble has been found in making this record by reason of the ordinary solar radiation thermometers finally breaking because of the tube not being long enough to accommodate the mercury when expanding to an unusually high radiation; 117° has been registered above the thermometer in the shade close by in February. Table No. 87 shows the record of solar and terrestrial radiation for a few days in January, February, March, November, and December, 1888.

The means of the month to which the daily readings in Table 87 pertain, so far as they can be made, are as follows:

(Fahrenheit °.)

	Max.	Min.	Solar rad.	Ter. rad.
January	42.7	10.0	....	....
February	53.0	25.0	40.3	....
March	49.0	27.0	55.5	11.8
April	73.3	40.6	46.9	....
November	48.6	24.7	53.7	8.8
December	49.0	17.8	56.4	10.1

In the preceding tabulations the column of solar radiation thermometer gives the difference between the maximum temperature of

the air in the shade and the highest temperature indicated by the solar radiation instrument placed in full sunshine. The reading of the latter instrument may be found by adding the numbers in the solar radiation and the maximum temperature column. The column of terrestrial radiation thermometer gives the number of degrees which that instrument falls below the minimum temperature of the air.

Observations with the ordinary glass globe vacuum solar radiation thermometers were discontinued in 1889 and the Arago-Davy actinometer substituted instead. The observations with that instrument for 1890 are included in the Third Annual Report of the Colorado Experiment Station; but in the absence of the reduction constants, which have not yet been determined, a comparison of the solar radiation with the soil temperature in 1889 and 1890 cannot be made.

In Table No. 83 the mean soil temperatures are given by weeks from January 1 to May 4. In reference to these temperatures it is stated that there are slight corrections of the thermometer which have been applied to the readings for 1890 but not to those of 1889. The differences tabulated, so far as the present discussion is concerned, are not great enough to seriously affect a comparison of the means.

In Table No. 84, the temperature of the air six feet above the ground, terrestrial radiation at three different elevations, mean soil temperatures, and snowfalls are compared for the whole year 1890. The mean soil temperatures are derived from the table of weekly means, and will vary slightly from a tabulation of actual monthly means by reason of the beginning and end of weeks not coinciding with the beginning and end of months. Hence the observations of one month in some cases lap into another in this table. The columns of mean terrestrial radiation illustrate the variation in mean temperature at various heights above the ground.

In Table No. 85 we have a tabulation of weekly soil temperatures from two sets of thermometers. Set B is placed in low ground near a ditch; set C is on a knoll in dry ground which is never irrigated. For a large portion of the year the water table is not far below the three-foot thermometer of Set B; this set is also subject to the influence of the irrigation water applied to the adjacent field. The soil at Set B is a dark loam, while Set C is in a hard, compact, yellow clay.

Studying this table it appears that in the warm months the soil temperatures range considerably higher in the dry ground, while in the cold months they range higher in the wet ground. Some of the reasons for this have been cited in the preliminary discussion, but by way of additional illustration Table No. 86, of evaporation from a water surface at Fort Collins, as determined by observing the loss from a galvanized iron tank three feet square and three feet deep, sunk flush with the ground, is also given. The high rate in June and July is

specially noticeable, as for instance in 1888, when for these two months the sum was 14.7 inches, which gives a daily rate for the whole time of 0.245 inch.

Records are also kept at Fort Collins of barometer, humidity, wind, sunshine, etc., but the foregoing are of more interest in discussing soil temperatures. The mean barometer is about 25 inches.

The Experiment Station at Auburn, Alabama (latitude 32°40′ north, longitude 85°30′ west; elevation above tide-water 826 feet), has made a series of soil-temperature observations during the last few years, from the record of which, as given in the several bulletins of the station, Tables No. 88 to 90 have been prepared. In Table No. 88 is given the maximum, minimum, and mean temperature of the air and soil for the months from October, 1888, to March, 1889, inclusive. The soil thermometers, of which the record is given in Table No. 88, are planted at the top of a hill in sandy soil frequently stirred during the growing season. Readings are made at 7 A. M., 2 P. M., and 7 P. M. A similar set of thermometers, of which the record is not here given, are also buried on the banks of a running stream in sandy bottom land. Some of the results of comparing the set in the bottom with those in the dry

TABLE No. 88.—TEMPERATURE OF THE AIR AND SOIL AT VARIOUS DEPTHS, FOR THE YEARS AND MONTHS INDICATED AT AUBURN, ALABAMA.

(Fahrenheit °.)

Months.	Air.			Soil, at depth of 3 inches.			Soil, at depth of 1 foot.			Soil, at depth of 2 feet.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1888.												
October	81	43.0	62.5	80.5	49 0	65.5	73.5	55.5	64.5	70.5	63.5	66.5
November	78	29.0	54.7	76.0	35.5	57.0	68.5	43.5	57.0	67.5	51.0	59.0
December	66	20.0	46.1	58.5	33.0	48.3	54.0	39.5	47.3	54.0	45.0	50.4
1889.												
January	67	23.0	46.9	....	....	47.3	....	....	46.7	....	....	49 2
February	75	16.5	46.3	....	....	46.8	....	....	45.8	....	....	47.7
March	76	30.0	54.7	....	....	56.4	....	....	53.5	....	....	53.4

Month.	Soil, at depth of 3 feet.			Soil, at depth of 4 feet.			Soil, at depth of 5 feet.			Soil, at depth of 6 feet.			Soil, at depth of 7 feet.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1888.															
October	71.0	65.5	68.0	72.5	67.0	69.5	73.0	68.0	70.0	73.0	68.5	70.5	73.0	69.0	71.0
November	67.0	55.0	62.0	67.5	58.5	64.0	68.0	61.0	65.0	68.5	62.0	66.0	68.5	63.5	66.0
December	55.5	49.5	53.0	58.0	52.5	55.2	60.5	55.0	57.5	62.0	56.0	58.7	63.5	57.5	60.1
1889.															
January	....	....	50.8	....	....	52.5	....	....	53.6	....	....	54.7	....	....	55.9
February	....	....	48.9	....	....	50.3	....	....	51.6	....	....	52.4	....	....	53.4
March	....	....	53.1	....	....	53.2	....	....	53.3	....	....	53.3	....	....	54.0

TABLE No. 89.—MEAN OF AIR, TERRESTRIAL, AND SOIL THERMOMETERS AT AUBURN, ALABAMA, IN 1889.

(Fahrenheit °.)

Month.	Mean air temp.	Mean ter. temp.	Mean soil temperatures at depths of:								
			3 ins.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.
January....	46.9	39.7	47.3	46.7	49.2	50.8	52.5	53.6	54.7	55.9	57.5
February ..	46.3	36.8	46.8	45.8	47.7	48.9	50.3	51.6	52.4	53.4	55.0
March	54.7	43.2	56.4	53 5	53.4	53.1	53.2	53.3	53.3	54.0	54.8
April	62.5	55.6	67.2	63.9	62.6	61.1	60.9	59.0	58.3	58.2	58.0
May	70.1	57.2	76 7	73.9	71.6	69.3	66.7	65.4	64.2	63.3	62.4
June	76.1	65.8	81.9	78.3	76.1	74.0	72.5	70.6	69.3	68.5	67.2
July	80.7	70.0	86.6	83.3	80.9	78.7	77.2	74.7	73.3	72.5	70.8
August	77.6	67.5	81.6	79.3	79.1	78.3	77 5	76.4	75.6	75.0	73.3
September .	74.8	65.2	78.4	77.0	77.8	77.2	77.1	77.8	75.6	75.0	73.8
October....	62.3	49.5	68.5	67.1	69.0	68.3	71.2	72.3	72.3	72.2	72.2
November..	53.1	42.9	56.2	56.2	59.6	61.6	63.5	64.7	65.7	66.6	67.0
December..	57.8	45.5	57.9	55.2	56.7	57.5	58.7	60.0	60.5	61.5	62.9

upland may be briefly referred to. Thus it is found that the same difference exists here as at Fort Collins between the temperature of upland and lowland soil, although the differences at usual temperatures are not as pronounced in Alabama as in Colorado. But when the air temperature falls below about 40°, at times the soil temperature in the upper layers ranges several degrees higher in the bottom than in the upland. The daily range of the bottom land is also less than that of the upland in winter, though, as may be expected, the daily range decreases with increase of depth.

In Table No. 89 the mean air, terrestrial, and soil temperatures are tabulated for the twelve months of 1889. In this series the soil-tem-

TABLE No. 90.—COMPARISON OF THE MAXIMUM AND MINIMUM AIR TEMPERATURE, OF TERRESTRIAL RADIATION, AIR AND SOIL THERMOMETERS, BY MONTHS FOR THE YEAR 1889; AT AUBURN, ALABAMA.

(Fahrenheit°.)

1889.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Max. air ther..............	**67.0**	**75.0**	**76.0**	**82.0**	**89.0**	**91.5**	**98·0**	**92.5**	**93.0**	**82.0**	**76.0**	**74.0**
Max. ter. ther..............	**51.0**	**66.5**	**54.0**	**62.0**	**63.0**	**74.0**	**73.5**	**72.5**	**78.0**	**60.0**	**60.0**	**59.5**
MAX. SOIL TEM.												
Depth of 3 in............	63.5	69.0	73.5	82.5	92.5	96.0	101 5	95.0	96.5	84.5	69.5	69.0
Depth of 2 ft....	52.5	57.0	58.5	67.0	76.5	80.0	86.0	82 0	89.5	74.0	65.5	60.0
Depth of 4 ft...........	53.5	53.0	56.5	63.0	71.5	75.0	79.5	79.0	84.5	74 5	69.0	60.5
Depth of 8 ft...........	59.5	56.5	56.0	60.5	62.5	69.0	73.0	73.5	76.5	74.5	70.0	65.0
Min. air ther..............	**23.0**	**16.5**	**30.0**	**38.0**	**45.0**	**46 0**	**67.5**	**63.0**	**48.0**	**38.0**	**24.0**	**29.0**
Min ter. ther........	**21.0**	**24.0**	**32.0**	**37.0**	**43.0**	**43.0**	**60.0**	**62.0**	**48.0**	**36.0**	**22.0**	**30.5**
MIN. SOIL TEM.												
Depth of 3 in.	33.5	32.0	37.0	48.5	52.0	52.0	71.5	69.5	54.5	45.0	35.0	35.0
Depth of 2 ft............	46.5	44.0	49.0	58.0	64.5	68.5	77.0	78.0	72.0	62.5	52.0	50.0
Depth of 4 ft............	51.5	48.0	50.5	56.5	63.0	69.5	74.5	77.0	75.0	67.0	58.0	56.5
Depth of 8 ft............	56.5	54.5	54.5	54.0	60.0	65.5	69.0	73.0	73 5	70.5	64.0	62.0

perature observations are carried to a depth of 8 feet, which is considerably deeper than most of those thus far made here.

In Table No. 90 the maximum and minimum air, terrestrial, and soil temperatures are contrasted. The value of this tabulation would be greater if solar radiation were included; but thus far solar radiation observations have not been taken at the Alabama Station.

The foregoing tables, from 78 to 90 inclusive, together with the analysis of the same, can hardly be considered other than a very inadequate presentation of the information which has been recently acquired in this country. Of necessity the discussion and tabulations have been considerably condensed in order to bring them within the limits of a single chapter. Observations have been made at a number of places in addition to those here cited, of which for lack of space no account has been taken in this paper. Whoever wishes to study the question at length will do well to consult the original data as found in the annual reports and bulletins of the several Agricultural Stations.*

Remedies for Frost.

The foregoing discussion has indicated why frost will probably in the colder climates of this country interfere with the successful use of broad irrigation and intermittent filtration in extreme winter weather, and we may next inquire what remedies, if any, can be applied. To this it may be answered that it is doubtful if broad irrigation can be made to work at all when mean winter temperatures are for any considerable period much below about 20° to 25°. The quality of the soil irrigated and its capacity for absorbing and retaining heat will, however, materially influence the result; sandy, gravelly soils undoubtedly admitting of successful irrigation at lower temperatures of the air than clay and humus. The amount of snow will be also to some extent a controlling factor. In regard to intermittent filtration, it can probably be successfully operated by good management down to a mean air temperature of about, or somewhat below, 20°; and when the mean falls

* The chief sources of information for the preparation of this chapter have been:

(1) An. Repts. of New York St. Ag. Ex. Sta. at Geneva, 1883–1890.

(2) An. Repts. Penn. St. Col., 1889–1890.

(3) Bulletin No. 7 of the Minn. Ag. Ex. Sta., Apr., 1889.

(4) An. Repts. Maine St. Col., 1889–1890.

(5) Fourth and Fifth An. Repts. of Neb. Ag. Ex. Sta., 1890–1891.

(6) First, Sec. and Third An. Repts. of Col. Ag. Ex. Sta., 1888, 1889, 1890.

(7) Meterological Bulletins of the Ala. Ag. Ex. Sta., 1889, 1890, 1891.

(8) Second An. Rept. of the South Carolina Ag. Ex. Sta., 1889.

The authors wish to especially acknowledge indebtedness to Dr. Peter Collier of the New York State Station at Geneva, to Professor Wm. Frear, of the Pennsylvania State College, and to Professor Louis G. Carpenter of the Colorado Station, for data furnished. Also to the directors of several of the other stations, who have furnished the reports and bulletins of their stations as soon as published.

much lower there are four remedies either of which may be applied, namely:

(1) At the approach of winter to cover the entire area with boards.

(2) To cover a portion only, as for instance a series of trenches, at the approach of winter.

(3) To artificially warm the sewage to such temperature as will admit of filtering without freezing under extreme climatic conditions and without any protective covering of the field.

(4) Where the topographical conditions admit of such treatment to lay the filtration area down with special sand trenches and permanent board covering as illustrated and described in Part II. of the Massachusetts Special Report.

As indicated in the preceding discussion of this chapter, and also in Chapter XIV., the areas can also be worked continuously during extreme cold weather, though with the chance always that the frost may interfere with successful operation. For an absolute guarantee against interruption in extreme temperatures either the protective covering or artificial warming may be used; which of these to adopt in any locality where special protection of some kind is indicated, will be chiefly a question of comparative cost.

Comparative Estimates.

By way of illustration let us assume favorable conditions for the construction of high-grade intermittent filtration areas; this assumption implying either a nearly level or gently sloping original natural surface to which sewage can be delivered by gravity. Assume coarse, clean mortar sand within such reasonable distance as to admit of transporting and placing at a cost not exceeding 50 cents per cubic yard. Also assume a daily flow of 1,000,000 gallons, which at 80 gallons per head per day will represent the sewage of 12,500 people. We will further assume that the conditions of purification will be satisfied when filtering at the maximum rate of 100,000 gallons per acre per day. At this rate 10 acres will be required, but for the contingency of allowing an occasional rest of the area we will prepare 15 acres, and for liberal surroundings will purchase a total of 25 acres. The estimated cost of this with the assumed favorable conditions may be put at:

25 acres of land at $250	$6,250
14 acres leveled, graded, and embanked, at $300	4,500
15 acres underdrained to depth of 5 feet, at $250	3,750
15 acres furnished with coarse sand 3 feet deep (50c. per cubic yard), at $2,400	36,000
Distribution carriers, tanks, straining arrangements, etc.	10,000
Barns, sheds, team, wagon, tools, etc.	2,000
Contingent expense about 12 per cent	7,500
Amount	$70,000

Annual cost of operation :		
1 foreman at $75 per month	$900	
4 laborers, each $35 per month	1,680	
Keeping team, repairs of tools, etc	400	
Annual cost of repairs and renewals	920*	
Amount	$3,900	
$3,900 capitalized at 4 per cent		$97,500
Total capitalization		$167,500

So for as present experience can guide us the foregoing may be considered an ample estimate of the cost of constructing and operating without any special winter protection a high-grade filtration area of the capacity indicated, favorable conditions being as stated assumed. The total capitalized investment per inhabitant served would be ($167,500 ÷ 12,500) = $13.40.

We may now consider the addition to the foregoing caused by reason of either a protective winter covering of the area or by artificial warming.

A protective covering for the whole area will require the providing and renewing of the necessary lumber for covering, the construction and maintenance of sheds for storing the same in summer, the providing of the labor for laying down the covering in the fall and taking up and storing in the spring. The first cost of the lumber and store sheds, with the capitalization of renewals, maintenance, and additional labor will constitute the addition to be made to the previous estimate in order to obtain the total capitalized cost under the new conditions.

We have assumed that the conditions of purification will be satisfied when filtering at the maximum rate of 100,000 gallons per acre per day ; accordingly, it will be necessary to provide covering for only ten acres. The amount of lumber per acre, including posts, joists, and deck boards, may be estimated at 55,000 feet B. M. We have then as additional first cost :

55,000 ft. B. M. coarse lumber at $16, which for 10 acres amounts to		$ 8,800
Sheds for storing same during summer		3,300
Total additional first cost of disposal works		$11,800
Additional annual cost of operation will be :		
Renewal of lumber and store sheds	$850	
Additional labor for putting down and taking up protective covering each year at $50 per acre	500	
Total additional cost of operation	$1,350	
$1,350 capitalized at 4 per cent		$33,750
Total additional capitalization		$ 45,550
Bringing forward the previous capitalization of		167,500
Total capitalization including protective covering		$213,050

* This amount, with the allowance of $1,680.00 per year for common labor, is considered sufficient to not only provide for ordinary repairs and renewals of buildings, tools, etc., but to further admit of changing the upper 2 to 3 inches of sand on from one to two acres each year ; this amount of annual renewal of sand being considered sufficient, as an average, in view of the liberal provision of surplus area which has been made.

In this case the total cost per inhabitant served will be ($213,050 ÷ 12.500) = $17.14.

For covering of trenches merely, the cost of lumber and store sheds will be only about one-third of that for complete covering as per last estimate. The amount of labor, however, will be somewhat greater, the whole cost leading to a final capitalization of $201,000, which represents a total cost per inhabitant of $16.08. The advantage of operation will probably be somewhat in favor of the complete covering.

For the case of artificial warming we will assume that the climatic conditions are such as to require sewage which reaches the disposal works in winter at a normal temperature of 45° to be warmed to a temperature of 65° for 45 days. 1,000,000 gallons daily raised from temperature of 45° to 65° is (1,000,000 × 8.34 × 20) = 166,800,000 heat-units required per day. We will further assume the evaporation of 10 pounds of water from 212° for each pound of coal consumed in the furnace, the temperature of the steam to be high enough to yield at least 1,000 heat-units per pound of water when recondensed in the radiating coils. On these assumptions 10,000 heat-units will be realized from each pound of coal consumed in the furnace. The daily consumption of coal becomes then (166,000,000 ÷ 10,000) = 16,600 pounds. Adding to this for warming station, operation of pump for returning water of condensation to boiler, etc., and we reach a total of 18,000 pounds = 9 net tons, as the daily use of coal under the conditions assumed.

We may then estimate the additional first cost as: For steam plant, including building, coal shed, boilers, foundations, and settings, connections, return pump and radiating coil, etc., complete, at $13,000.

Additional cost of operation, on an average will be:

9 net tons of coal per day for 45 days, at $3.50 per ton	$1,417.50	
Additional labor for 45 days	180.00	
Renewals and repairs of steam-heating plant	600.00	
Total additional cost of operation	$2,197.50	
$2,197.50 capitalized at 4 per cent gives		$54,937.50
Amount		$67,937.50
Bring forward previous capitalization		167,500.00
Making the total capitalization for artificial warming		$235,437.50

For intermittent filtration, assisted by artificial warming in winter, the total cost per inhabitant served will therefore be, for the assumed case, $18.84.

For complete comparison of methods of sewage disposal we may

also estimate the cost of purifying 1,000,000 gallons per day by chemical treatment. For such works the estimate may stand as follows:

5 acres of land at $250		$1,250
Disposal works plant, including buildings, precipitation tanks, sludge press, air compressor, grinding and mixing machinery, pumps, etc., complete		30,000
Contingent expense, about 12 per cent		3,750
Amount		$35,000
Annual cost of operation:		
Superintendent at $100 per month	$1,200	
Steam engineer, fireman, and 3 laborers at $225 per month	2,700	
Fuel, water, oil, and waste	1,000	
365 million gallons of sewage treated annually at $12 per million gallons for chemicals	4,380	
Disposal of sludge	300	
Repairs and renewals of buildings and plant	1,600	
Amount	$11,180	
$11,180 capitalized at 4 per cent		$279,500
Total capitalization		$314,500

For chemical purification the total cost per inhabitant served is therefore found to be, under the assumed conditions, $25.16.

For intermittent filtration with a permanent board covering of specially prepared trenches, as per experimental field at Lawrence, the comparative estimate of first cost for purification of 1,000,000 gallons daily may stand as follows:

25 acres of land at $250	$6,250
20 acres underdrained at $300 *	6,000
For excavating trenches 2 feet wide and 2.5 feet deep in 20 acres, including removal of surplus material (trenches to be 5 feet apart), 1,630 cu. yds. per acre, at 20c. = $326 per acre	$6,520
For replacing the excavated material from said trenches with coarse sand at 50c. per cu. yd. 20 acres, at $815	16,300
For furnishing and laying for 20 acres the permanent board covers of coarse lumber = 360 M. ft.B. M. at $24	8,640
Distribution carriers, tanks, straining arrangements, etc.	10,000
Barn, shed, team, wagon, tools, etc.	2 000
Contingent expense, about 12 per cent	6,790
Amount	$62,500
Annual cost of operation:	
For this system the total may be taken at $4,300, which capitalized at 4 per cent gives	$107,500
Total capitalization	$170,000

* In this case a somewhat greater area may be assumed as necessary by reason of only a portion of the total content of soil to any given depth being actually in service. The cost of underdraining will also be somewhat greater than in the previous cases, due to greater depth of excavation requiring to be made. In the previously considered cases the drains are considered as laid after the leveling of field has been completed and before placing of the 3 feet of coarse sand, requiring under these conditions only 2 feet excavation for drains to be at depth of 5 feet when area was complete.

From which we deduce a total cost per inhabitant of $13.60, an amount, it will be noted, subtantially the same as for intermittent filtration with specially prepared sand area, without any protective covering. Moreover, it is important to remember that this estimate provides 20 acres of filtration area, which gives, when the whole area is in service, a daily mean rate per acre of 50,000 gallons.

Although not necessary for the argument we may still properly consider for full completion of the subject two other cases in intermittent filtration, as for instance : (1) When good material is so entirely available *in situ* that preparation of artificial area by bringing coarse sand from a distance is unnecessary ; and (2) the case when some little sorting and selecting of material at hand will suffice for the preparation of an efficient filtration area. We will base our estimates, as before, on the disposal of a daily flow of 1,000,000 gallons.

In the first of these two cases we will assume the preparation of 20 of the 25 acres purchased at a total cost of, including first cost of land as before, together with levelling, embanking, underdraining, construction of barns and sheds, teams, wagons, and tools and for contingent expense, an amount of $32,700. Expense of operation will be the same as in the previous estimates ; whence we reach a final total capitalization of $130,200, which gives again per inhabitant served, $10.42. In the same way for the second case the total cost per inhabitant will be $11.42.

Taking into account all of the foregoing comparative estimates it appears that even when liberal allowance is made for artificial warming, which is also found to be the most expensive method of insuring successful winter purification by intermittent filtration, we may still purify our assumed quantity of 1,000,000 gallons daily flow at no greater expense than by chemical treatment. For many localities the cost of intermittent filtration will be far below that of chemical treatment. Indeed, as between intermittent filtration with artificial warming in winter and chemical treatment the estimates show a difference in total cost per inhabitant served of ($25.16 — $18.84) = $6.32 in favor of the intermittent filtration. We must remember, however, that our estimate of cost of an intermittent filtration area was based upon fairly favorable conditions ; if we assume unfavorable conditions we may increase the original capitalized cost of filtration area with artificial warming in winter from $18.84 to about $22.00 per inhabitant served, which still leaves a balance of $3.16 in favor of high-grade, and artificially warmed, intermittent filtration.

Again if we refer to the estimate of annual cost of operation with artificial warming it will be observed that coal is estimated at $3.50 per ton, whereas in the vicinity of the coal regions it will be obtained at considerably less, in some places as low as $1.25 per net ton. On

the other hand, a few of the items of cost of chemical treatment will probably be somewhat less than used in the estimates in many localities.

As a general statement based on present information we may therefore say that intermittent filtration under the most unfavorable circumstances and in the severe climate of our northern winters will not exceed, when all the items are taken into the account, the cost of purification by chemical treatment. This statement, it will be remembered, is based upon delivery of the sewage at the purification area or station by gravity. In case it becomes necessary to include the additional cost of pumping to an elevated filtration area the balance, as a matter of total capitalization, may be in favor of chemical purification.

Again no account is taken of relative length of main outfall sewer required to reach the point where the purification is applied, the assumption being the use of the same location in either case. Experience indicates, however, that frequently the finding of a favorable filtration area necessitates going further away than for the location of a chemical purification station. In such cases with relative costs of outfall sewer included in the capitalization the balance may also as a matter of total cost lie in favor of chemical purification.

The present discussion is not concerned, except incidentally, with the comparative efficiency of the various methods of sewage purification — the Lawrence experiments appear conclusive on that point; and it may be merely remarked that the chemical treatment obtained at the foregoing expense would be somewhat less efficient than that obtained by intermittent filtration even in winter; for the whole season the mean efficiency of the chemical treatment would be far below that of the intermittent filtration.

Deductions.

In conclusion, by way of summary, we may say:

(1) That any place with a mean temperature of the air for the coldest winter month not lower than about 20° to 25° F., and with sewage distributed to the purification area at a temperature not lower than 45° F., the purification of sewage by broad irrigation may probably be effected without serious interruption from frost, although winter purification will be somewhat less efficient than that during the warm months. Below a mean temperature of 20° to 25° F. purification by broad irrigation will probably be interrupted considerably by frost.

(2) Purification by intermittent filtration can probably be sucessfully worked at a lower temperature than broad irrigation. As a safe limit we may set the lowest mean air temperature at about 18° to 20° F.

(3) The quality and temperature of the soil to be used will materially influence the result, and before deciding what can be reasonably expected in any given locality we need to know the physical properties of the soil to be used as well as the mean temperature of the air during the winter months.

(4) As a corollary to (3) we may say that sandy soils are preferable for broad irrigation and intermittent filtration, not only on account of their open texture, but because of their greater capacity for retaining heat; clay and humus are, on the contrary, the poorest soils for this purpose by reason of their relatively low capacity for retaining heat. The close texture of clay also constitutes another serious objection to its use.* The great desideratum of successful sewage disposal by broad irrigation or intermittent filtration in winter is a medium which, acting in conjunction with the water, will prolong to the utmost limit the time of congelation. Sand answers to this condition better than any other material.

(5) The capacity of a filtration area to absorb and retain heat in winter will be increased by making the upper surface an inch or two in depth of coarse black sand or dark-colored gravel.

(6) It appears that the climate of the greater portion of the United States will admit of ordinary open intermittent filtration in the average winter. Exceptions to this are however found in portions of the northern belt of States.

(7) In general we may say that in any of the Middle, Central, and Southern States a very efficient purification can be attained by broad irrigation and intermittent filtration at all seasons of the year.

* There is a reason, however, why clay may be of value as a sewage purification medium, namely, its peculiar behavior with reference to urine.

Professor Way, in his investigation on the Power of Soils to Absorb Manure, Jour. Roy. Ag. Soc. of Eng., vol. xi., p. 366, describes the following experiment:

Three quantities of fresh urine of 2,000 grains each, were measured out into similar glasses. With one portion its own weight of white sand was mixed; with another its own weight of white clay; the third being left without admixture of any kind. When smelt immediately after mixture, the sand appeared to have no effect, while the clay mixture had entirely lost the smell of urine. The three glasses were covered lightly with paper, and put in a warm place, being examined from time to time. In a few hours it was found that the urine containing sand had become slightly putrid; then followed the natural urine; but the quantity with which the clay had been mixed did not become putrid at all, and at the end of seven or eight weeks it had only the peculiar smell of fresh urine, without the slightest putridity. The surface of the clay, however, became afterward covered with a luxuriant growth of confervæ, which did not happen in the other glasses.

Professor Way likewise found that filtering urine through clay prevented putrefaction and kept the urine as if fresh for a month or more.

Professor S. W. Johnson, cites the foregoing experiment of Professor Way in his How Crops Feed (p. 393), and discusses at length the conditions under which the nitrogen of urine is absorbed and assimilated by vegetation. As the result of his own and the researches of other agricultural chemists whose investigations are cited, Professor Johnson concludes that it is not necessary for the nitrogen of urine to undergo nitrification, but that immediately, or after undergoing a slight but easy alteration, it may be taken up and assimilated by growing plants. The absence of bad smells from well-managed sewage farms is probably largely explained by Professor Way's experiments.

(8) In localities where the climate is too severe for purification by ordinary open intermittent filtration the efficiency of the process may be considerably increased by covering the area, either partially or wholly, or by artificially warming the sewage before application.

(9) Other things being equal purification by high-grade intermittent filtration is cheaper than purification by chemical precipitation. As a general statement we may say that this still holds true even in severe winter climates where special protection of the filter area or artificial warming is required.

CHAPTER XVIII.

ON BEGGIATOA ALBA AND ITS RELATION TO SEWAGE EFFLUENTS.

Mr. A. W. Bennett has given in a paper on "Fungi Found in Sewage Effluents," read before the American Society of Microscopists in 1884, an account of *Beggiatoa alba* as developing in immense quantities in several sewage effluents in England. Inasmuch as this organism is found in this country a short account in the way of extracts from some of the literature may be properly given in this place. Mr. Bennett says:

This organism occurs abundantly in the effluent water from sewage works, and is well known to English sanitary engineers under the name of the "sewage fungus." It forms dense, flocculent, grayish-white masses attached to the bottom and side of the channel, or to ordinary green algæ. Under the microscope it is seen to consist of an immense quantity of colorless threads, with but little or no chlorophyll, full of granular protoplasm, and containing a number of bright, strongly refractive, globular particles; it is the *Beggiatoa alba* of Vaucher, but differs slightly from the typical form described by Zopf (Spalt-pilze, p. 76). The filaments are branched, either dichotomously or laterally, and situated either at the base of the branches or elsewhere, and the cells are frequently remarkably constricted, both above and below the septa. The globular refringent particles have been determined by German experimenters to consist of pure sulphur, and are most commonly situated immediately below each septum, but sometimes towards the centre of a cell, or more generally diffused.

The systematic position of *Beggiatoa* is somewhat obscure. Zopf places it, without hesitation, among the lowest section of fungi, the Schizomycetes, which form one division of Sachs' primary class of Protophyta. It may, in fact, be regarded as the Leptothrix condition of an organism of this class, having also its corresponding bacillus, coccus, and spirillum conditions. On the other hand, it appears to be closely allied to the Oscillatoriæ through Crenothrix.

The source of the globules of sulphur contained in this organism is a very interesting question. The *Beggiatoa* is not necessarily indicative of partially decomposed sewage; it occurs also in the effluent water from manufactories, especially from sugar factories, tanneries, etc., thermal sulphur springs, as well as in drains. Luerssen (Die Kryptogamen, p. 24), gives as its habitat putrid water, noisome ditches, the effluents of manufactories and mineral springs, especially all thermal sulphur springs, as those of the Alps and Pyrenees, Aix la Chapelle, baths of Vienna, etc. It appears, therefore, to have the power of extracting sulphur, not only from decomposing organic matter, but also from the mineral sulphates dissolved in spring water. Sulphur may be set free in this way by the mutual decomposition of soluble sulphides and sulphites. Independently of the source of sulphur in the organic matter present in the sewage itself there is an abundant supply of this element in the substances used for purifying or precipitating the sewage, which are usually sulphate of alumina, lime, and proto-phosphate of iron.

The growth of the so-called "sewage fungus" must undoubtedly, therefore, be regarded as evidence of the presence in the water of an abnormal amount of sulphates, derived either directly from sewage or from the substances used in precipi-

tating it, or in other ways in manufactories. But there seems no reason to believe that it will itself have any injurious effects on the water. It is difficult to see how the sulphur, once set free, can again combine with hydrogen to form sulphuretted hydrogen gas as long as the organism is growing in the water. Indeed, if allowed to accumulate and periodically removed, it may tend to purify the water by abstracting from it some of the undue proportion of sulphur.

At the Merton sewage disposal works of the Croydon, England, Rural Sanitary Authority, the *Beggiatoa alba* has been the subject of interesting legal proceedings. The outfall from these works discharges into a large pond at the head of a bye-wash from whence the effluent flows into the river Wandle. After the discharge into the pond had continued for some time, complaints were made by adjoining proprietors that the pond had become the source of a serious effluvium nuisance, and one of the riparian owners sought to restrain the Sanitary Authority from discharging the effluent into the pool. An examination disclosed the fact that *Beggiatoa* grew extensively in the underdrains and was constantly breaking away and flowing out in the effluent, accompanied by enormous quantities of vorticella.

Mr. Justice Denman, who before deciding the case himself actually viewed the alleged nuisance, in his decree, says :

> The water which flows into the bye-wash (and here I speak partly from personal observation) contains in it a very large quantity of what is called sewage-fungus. The evidence about that substance was interesting and curious. . . . It was said to be without odor whilst alive, but when dead to be capable of giving off sulphuretted hydrogen, and so becoming foul to the nose. My own observation of what was happening last Tuesday, coupled with the appearances in the pond itself, and the evidences of the witnesses, entirely confirms this account. . . . I have no doubt whatever that that pond, which was proved to have been clear within the last four or five years, and good for perch, has been turned into a very filthy pond mainly by this agency. . . . It is, I think, as plain as anything can be, that a continual discharge, such as I myself saw running into the pond in large quantities, is "a discharge of sewage or filthy water" not free from all foul or noxious matters, such as would affect or deteriorate the purity and quality of the water in the bye-wash, but that it has seriously affected and deteriorated it, and must inevitably do so.

A decree of perpetual injunction was granted, restraining the Sanitary Authority from polluting the pond and imposing a fine of $1,000. To obviate this difficulty fungus filters were constructed, and the Sanitary Authority acquired the pond and the upper part of the bye-wash.

CHAPTER XIX.

THE EFFECT OF THE POLLUTION OF STREAMS BY MANUFACTURING WASTES UPON THE LIFE OF FISH.

THIS division of our subject, while of considerable importance, has furnished as yet comparatively little detailed information upon which to base conclusions. The principal investigations thus far are: (1) Those of Penny and Adams in Scotland; (2) those of Saare and Schwab in Germany, and (3) a few made under the direction of the United States Fish Commissioner in this country. The following gives some of the more important results of Penny and Adams' experiments.

PENNY AND ADAMS' EXPERIMENTS.*

In order to determine the effect of various substances upon fish, two kinds were selected, namely, the minnow and the goldfish. These two kinds of fish are stated to possess different temperaments, the minnow being remarkable for its delicate vitality and for the fine sensibility it evinces toward all kinds of disturbing influences; the goldfish, on the other hand, is comparatively tenacious of life, and possesses a sluggishness of nature that permits sufficient length of time for observing the action of poisonous agents.

Before beginning the experiments, a sufficient stock of fish was secured and stored under such conditions as to satisfy the experimenters that the fish to be experimented upon were in a healthy state.

The experiments included a trial of a number of the acids, sulphuric, nitric, muriatic, etc.; of the mineral salts, sulphate of copper, chloride of lime, acetate of lime, etc.; the special chemicals, chlorine, iodine, etc.; of sumach, madder, logwood, etc.; and various miscellaneous polluting matters, such as furnace-cinders, blood, and coal-tar.

Of the mineral acids, the nitric and sulphuric, when present in the proportion of 1 part to 50,000, killed minnows; but goldfish lived in the same proportion. In muriatic acid, both lived in a mixture of 1 part to 50,000.

Tannic acid killed a minnow in the proportion of 1 part to 14,000, and a goldfish with 1 part to 7,000. In gallic acid, 1 part to 7,000, both died, while in 1 part to 14,000 both lived.

* Fourth Report of the Rivers Pollution Commission, vol. ii., pp. 377–391.

In acetic acid, a minnow lived 20 hours before succumbing in a mixture of 1 part to 8,750; a goldfish lived in a proportion of 1 part in 3,500 for 20 hours, and survived.

In carbolic acid, a minnow, in one case, subjected to the action of 1 part in 70,000, died in 40 minutes. A goldfish died in 1 part in 3,000 but lived in one part in 7,000.

The most virulent of the metallic salts was sulphate of copper. Both minnows and goldfish died in a mixture of 1 part in 100,000; both lived in a mixture of 1 part in 200,000.

Sugar of lead, alum, salts of iron and potash are all destructive of fish life in about the same proportion, namely 1 part in 4,000. The salts of potash, the bicarbonate, red prussiate, and yellow prussiate are comparatively harmless; both kinds of fish lived in all these in a mixture of 1 part in 500. With carbonate of soda a minnow died in 1 part in 17,500, and lived in 1 part in 35,000; a goldfish lived in 1 part in 17,500.

In a saturated solution of chloride of lime a minnow died in 1 part in 16,000; both lived in 1 part in 21,000.

In a saturated solution of chlorine both lived in 1 part in 2,000. Iodine and bromine killed in a mixture of 1 part in 35,000.

Caustic potash, when present in 1 part in 35,000, destroyed a minnow; a goldfish was destroyed by 1 part in 7,000, but lived in 1 part in 35,000.

Galls killed a minnow in 1 part in 2,808, and goldfish, 1 part in 936.

Sumach and madder solutions both killed a minnow 1 part in 7,000. In sumach solution a goldfish lived in 1 part in 7,000, but in madder of the same strength died.

In boiled logwood chips both kinds of fish lived in 1 part in 2,800; in logwood extract both lived in 1 part in 8,750.

Linseed oil was found entirely innocuous as regards fish life.

In a solution of crude soap, 1 part in 8,750, a goldfish lived for twenty hours and showed no after ill effects; in double that strength a strong fish died in six hours.

TABLE No. 91.—GENERAL RESULTS OF PENNY AND ADAMS' EXPERIMENTS ON FISH.

Class of agents.	No. of agents.	No. of fish.	Total No. of fish.		Goldfish.		Minnows.	
			Died.	Lived.	Died.	Lived.	Died.	Lived.
Water	6	36	..	36	..	3	..	3
Acids	11	35	35	20	13	15	22	5
Metallic salts	16	61	28	33	4	13	24	20
Special chemicals	7	30	23	7	7	3	16	4
Drysalteries	10	132	20	112	8	38	12	74
Miscellaneous	11	77	60	117	11	13	49	4
Waste discharge	10	37	8	29	1	20	7	2
Totals	71	428	174	254	44	105	130	119

Ashes and ordinary furnace cinders were found to be specially deleterious. With 500 grains of furnace ashes to a gallon of, or 1 part to 140, water a minnow died in 45 minutes and a vigorous goldfish in five and one-half hours.

Coal-tar killed a goldfish in 1 part in 8,750.

Heavy pitch-oil killed both minnow and goldfish, 1 part in 35,000; a goldfish lived 1 part in 70,000. In naphtha a minnow lived in 1 part in 8,750.

The general results of these experiments are given in Table No. 91.

Saare and Schwab's Experiments.

Saare and Schwab experimented upon tench and trout. They found that liquids containing from 0.04 to 0.005 of one per cent. of a bleaching solution were fatal to tench, while a solution of 0.0008 were fatal to trout. The action of the chlorine, which is the destructive agent in bleach liquids, was found to be increased by the presence of an acid.

Mercuric chloride was fatal in proportions of 0.1 to 0.05 of one per cent. Copper sulphate in 0.1 and 1.0 per cent. killed trout in a few minutes. Potassium cyanide killed in the proportion of 0.01 to 0.005 per cent.

Carbolic acid was found fatal to trout in proportions between 0.01 and 0.005 per cent.*

Experiments of the United States Fish Commission.

A number of papers in regard to the influence of the pollution of streams upon the fisheries have appeared in the publications of the United States Fish Commission, the more important of which are as follows:

(1) A translation of a paper on The Injurious Influence on Pisciculture of the Retting Water of Flax and Hemp, by E. Reichard, of Jena,† in which are given the results of a series of experiments on the immersion of a tender fish, like the whiting as found in the river Salle, and a less delicate fish, the bastard carp, in mixtures of various proportions of clear water and retting water. The retting water used was obtained by soaking flax 5 days.

In 1 part retting water and 3 parts running water the fish immediately showed signs of uneasiness and both died in the course of 12 hours. A repetition of the experiment gave the result that the fish died in 3 hours.

A large bastard carp lived in a 3 to 1 mixture for two days, but lost

* For Saare and Schwab's experiments in detail, see *Archiv für Hygiene*, vol. iii., Part I., p. 81.

† Ann. Rept. U. S. Fish Commissioner, 1880, pp. 545-550.

its color and gradually grew weaker; and although again placed in running water, died after 8 days.

In 1 part retting water and 9 parts running water the fish quickly showed signs of sickness. After 24 hours in the mixture, they were again placed in running water, where they died in a few days.

In 1 part retting water and 2 parts running water small fish died very soon. A large bastard carp was at the point of death in 42 hours; it was then removed and placed in pure running water, where it partially recovered, but died in two weeks.

In a mixture of 1 part retting water, 14 days old, and 4 parts fresh water the fish died in 36 hours.

Fish placed in a mixture of 1 part retting water, 3 weeks old, and 4 parts fresh water became sick and changed their color, but revived on transfer to fresh water after a few days.

(2) In a report by Marshall McDonald, on the Pollution of the Potomac river by the Discharge of Waste Products from Gas Manufacture,* the point is made that even though the discharge of the waste products should seem to have no injurious effect in driving the larger fish away, yet such discharge and the consequent deposits upon the bottom may, by destroying their food, make impossible the development and growth of young fish. In the case examined the discharge into the river amounted to at least 100 gallons per minute of the waste products of gas manufacture; and the conclusion at which Mr. McDonald arrives is that the bottom of the stream is affected by the deposited matter for a distance of several miles.

(3) A report was by Mr. McDonald upon the Effect of Waste Products from Page's Ammoniacal Works upon Young Shad Fry.†

A series of experiments were made with mixtures of the wastes from the Ammoniacal Works in Potomac river water of various degrees of strength, with the result of showing that a distinctly deleterious influence is exerted when the waste products are present to the amount of 1 gallon to 400 gallons of the river water. The following gives the detail of the three last experiments of the series:

One hundred newly hatched shad were put in 20 ounces of mixture, 0.5 per cent. strength ($\frac{1}{2}$ part refuse and $99\frac{1}{2}$ parts water) at 2 P.M., June 2; at 6 P.M., 9 fish dead; 6 A.M., June 3, 16 fish dead; 6 A.M., June 4, 25 fish dead, and remainder weak; 6 P.M., June 6, all dead.

One hundred newly hatched shad were put in 20 ounces of mixture, 0.25 per cent. strength (0.25 part refuse and 99.75 parts water) at 2 P.M., June 2; at 6 P.M., all well; 6 A.M., June 3, four fish dead; 6 A.M., June 5, 16 fish dead; 6 P.M., June 6, 57 fish dead; 6 A.M., June 7, all dead.

One hundred newly hatched shad were put in 20 ounces of Potomac

* Bulletin of the U. S. Fish Commission, vol. v., pp. 125-126.

† Bulletin, etc., vol. v., pp. 313-314.

water at 2 P.M., June 2; but few were alive at noon on June 8, and the few showed but little vitality.

Mr. McDonald observes that newly hatched shad are much less sensitive to the injurious influences in the water in which they are, than are the same fish after their sacs have been absorbed and they have begun feeding.

It is also suggested that the minute food of young shad is more sensitive to injurious influences than are the young fish which feed upon them.

The authors' observations upon the haunts of minute life of various kinds is corroborative of this observation, and undoubtedly one very marked effect of stream pollution, as regards the life of fish, is the driving away or destruction of many kinds of favorite food.

Experiments have shown that alewives, which are epecially sensitive to sewage pollution, will live in perfect health for an indefinite period in the effluents from intermittent sand filters. The same fish died when placed for a short time in the effluents from chemical processes.

CHAPTER XX.

CONCLUSIONS TO PART I.

THE Royal Commission on Metropolitan Sewage Discharge remarks in its second report that the satisfactory solution of sewage disposal problems is a matter of extreme difficulty. The additional remark may be properly made that sewage disposal will always be a matter of considerable expense. As a problem in economics, therefore, the question may be stated somewhat as follows:

Having given a specific case of sewage disposal, it is required to determine the method of treatment or purification which will best satisfy all the attendant sanitary conditions whatever they may be; expense so far as compatible with the foregoing to be kept at a minimum.

When stated in this form it at once becomes apparent that the solution of sewage disposal problems will require the highest skill of trained sanitary specialists.

As regards the various methods of disposal discussed in the preceding chapters it may be stated by way of final conclusion, that:

(1) Discharge into tidal or other large body of water will be ordinarily, independent of other considerations, the cheapest method of disposal. Such discharge should never be permitted into bodies of fresh water which are the sources of public water-supplies at any point within the influence of the sewage. The range of influence in streams has been defined in general terms in the preceding chapters.

Moreover, in order to obtain the best results from the self-purification processes, the quantity of water into which raw sewage is discharged should always be large enough to dilute the sewage from thirty to fifty-fold.*

(2) Sewage may be greatly improved by chemical treatment but we have as yet no reason for supposing either that chemically purified sewage is fit to drink or even that it may be safely permitted to flow into streams used as public water-supplies. Other things being equal, the expense of chemical purification will be greater than that of either broad irrigation or intermittent filtration.

With reference to American conditions it may be stated as a general

* See Eng. Record, vol. xxvi., No. 24 (Nov. 12, 1892), p. 380, "Purification of Sewage by Microbes."

proposition that chemical treatment only applies in those places where land purification is impracticable.

(3) Broad irrigation offers a rational and efficient method of sewage purification, although the relatively high price of common labor in this country will limit its application here. The use, however, of the silo for preserving the large forage crops naturally produced by sewage farming, and the consequent extension to dairying, will be likely to lead to its gradual adoption in the more thickly settled portions of the country. In the arid regions of the West the scarcity of water has already led to a considerable development of sewage irrigation, as we have indicated in detail in Chapter XLIV., in Part II.

From an economic point of view a marked advantage of broad irrigation is that the sum realized from the sale of the produce assists in reducing the net cost of the purification. The most marked disadvantage is that the sewage must be cared for in all sorts of weather, whether required for the crops or not. While, therefore, it is impossible to say that broad irrigation can always be conducted at a profit, it is nevertheless true that it will offer in many cases a cheap and efficient method of sewage purification. The probable limit of temperature at which it can be carried on in winter has been indicated in Chapter XVII.

(4) Taking into account all the elements of the problem, intermittent filtration is the most practicable method of purifying sewage thus far worked out. Its effluents, when the best possible standard is maintained, may flow without prejudice into streams used as public water-supplies, while the moderate areas required for its application permit its use in the majority of cases where any sort of purification is required.

As regards the use of intermittent filtration in winter, we may predicate from present information a fairly successful purification from properly managed areas, even in extreme cold weather.

PART II.

DESCRIPTIONS OF WORKS.

CHAPTER XXI.

PAIL SYSTEM AT HEMLOCK LAKE.

THE domestic water supply of the city of Rochester, New York, is obtained from Hemlock lake, in the County of Livingston, about 30 miles southerly from and at an elevation of 386 feet above the city.

Hemlock lake is about seven miles long and $\frac{3}{4}$ mile wide. It occupies the northern extremity of a deep, narrow valley, 15 miles long. The shores of the lake are bluff and steep, rising to a height of from 300 to 700 feet, and along the beach are mostly covered with a growth of timber. The average depth is over 40 feet.

About the time at which Hemlock lake was utilized as a source of water supply for the city the attention of the citizens of Rochester, as well as those of surrounding cities and towns, was attracted to the lake as a desirable point for summer residence.*

In 1892 there were in use about 120 cottages and several hotels or summer boarding-houses, and the summer population, including transient visitors, was from 800 to 1,000 persons.

The gradual growth of this large summer population, living directly on the shores of the lake, and using it not only as the source of water supply but also allowing all refuse substances, including contents of privies, to drain into it, had its natural effect in a probable marked deterioration of the quality of the water,† and the necessity for an efficient sanitary protection of this watershed accordingly became self-evident. In the spring of 1885 a complete sanitary survey was made and sketch plans prepared of every source of pollution about

* See 16th An. Rept. of the Ex. Bd. of the City of Rochester for estimates in detail of permanent and transient population in the various cottages, permanent residences, hotels, etc. During July and August there is stated to be, probably, a constant population of about 1,200, which is largely increased on holidays and by special excursions.

† See (1) On the Micro-organisms in Hemlock Water, by Geo. W. Rafter (1888); and (2) A Report on an Endemic of Typhoid Fever at Springwater, N. Y., in October and November, 1889, by Geo. W. Rafter and M. L. Mallory (1890).

the lake. At the same time the State Board of Health, under the provisions of the act already referred to on page 71 formulated rules and regulations for the sanitary protection of this water-shed (see Appendix III.). These regulations provide: (1) That privies, pig-pens, and barn-yards shall not be located over or adjacent to any stream, spring, or dry water-course tributary to the lake, where the contents can reach the lake; (2) that any privy situated within 50 feet of any spring, stream or dry water-course, or ravine, must be constructed without a vault, and provided under the seats with water-tight receptacles for night-soil, which shall be frequently removed, emptied, cleaned, and returned, and the contents buried in the earth in such a manner that they cannot reach any water-course or permanent level of subsoil water.

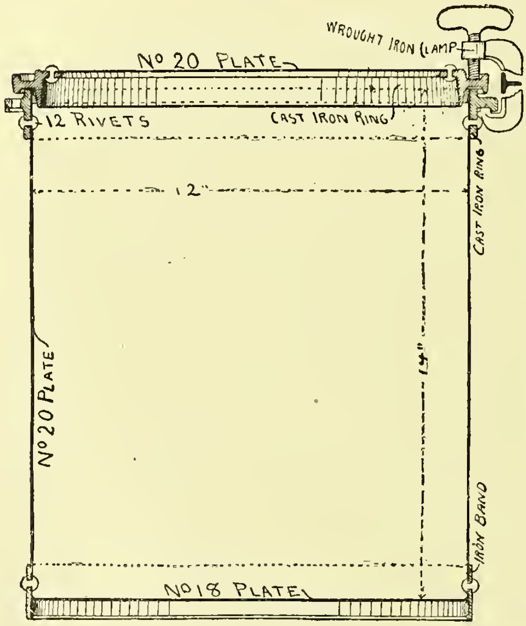


Fig. 30 A.

Further, no manufacturing waste is allowed to be discharged or drained into any spring, stream, or dry water-course on said water-shed. The same restriction applies to depositing dead animals, birds, fish, decayed fruit, leaves, sawdust, roots, branches or trunks of trees in any spring, dry water-course, or in the lake itself. The washing of sheep or other animals in the lake or any of its tributaries is also prohibited.

The provisions relating to houses, cottages, tenements, tents, and picnic grounds within 200 feet of the shores of the lake may be summarized as follows: Each property is furnished with at least one privy set upon the surface of the ground, without a vault, and so constructed that metallic pails, 15 inches high by 15 inches in diameter, can be placed under the seats and easily removed with their contents. This pail is shown by Fig. 30 A.

The occupants are required daily to add dry loam in small quantities, as a deodorizer and absorbent. It is also made the duty of the occupant to provide a receptacle for garbage and to place the same therein. Slop or wash water is to be scattered upon the surface of

the ground at a distance from either the lake, or any ravine or water-course, and the points at which slops are deposited frequently changed.

Animal manures from stables are to be deposited in tight covered receptacles and the contents frequently removed.

The city of Rochester furnishes under the rules a sufficient number of metallic pails for the use of each privy within 200 feet of the lake and is required to remove, empty, cleanse, and disinfect the same as often as necessary. Whenever a full pail is removed an empty one is supplied in its place. The pails during removal are provided with air-tight covers, so that no odor can escape. The contents of the pails, together with the dry garbage, are removed to a point below the foot of the lake and buried.

In practice, the night-soil and garbage is collected and removed to the foot of the lake by means of a broad, flat-bottomed steamboat, the collections being usually made in the early morning. From the steamboat landing at the foot of the lake the night-soil and garbage are transported by a tramway about 1,800 feet to the sanitary building and disposal grounds, where it is treated as follows : Narrow trenches are excavated, care being taken that the permanent level of the sub-soil water is not reached, and the contents of the pails are deposited therein in thin layers, and immediately covered with dry loam to a depth of six inches. This process is repeated day by day until the trench is nearly filled, when the balance is rounded up with earth and a new trench started. The location of the trenches is recorded, the surface cultivated and cropped, and after a suitable period the same land again used. A trench 500 feet in length has proved sufficient for a year's operation, and as these trenches need not be more than three feet apart, a small area is sufficient for the purpose.

The cans, as emptied, are taken to a sanitary building, which is provided with an elevated tank filled with a solution of copperas, and other necessary appliances for washing, cleansing, deodorizing, and drying the cans. The cans are constructed of heavy galvanized iron, coated, inside and out, with black asphalt varnish. In cleansing the cans, if necessary, more active deodorizing and disinfecting agents than copperas are employed.

The process has been so conducted that local prejudice has subsided and fears as to possible offensive odors in the neighborhood allayed. In the sanitary building and about the grounds no offensive odors are discernible, although during the year 1890 the contents of 3,128 cans and 80 tubs of garbage were thus removed and treated.*

* See (1) Paper by J. Nelson Tubbs in Proceedings of the 11th. An. Meeting of the Am. W. Wks. Assn. (Cleveland, 1888), pp. 18-23.

(2) The several An. Repts., Roch. W. Wks., 1886 to 1892, inclusive.

(3) Eng. and Bldg. Rec., vol. xxii., p. 412 (Nov. 29, 1890), where illustrations of appliances may be found, and from which Fig. 30A has been taken.

In connection with the disposal by burial of this refuse organic matter from the habitations on the shores of Hemlock lake, it may be of interest to note that the soil in the trenches which were filled one, two, and three years before, was examined in November, 1890, to ascertain whether complete decomposition had taken place. The excavations disclosed the following facts: In trench No. 3, used in 1888, no quicklime was employed to hasten decomposition; nevertheless the soil exhibited no trace of putrescible matter, either by appearance or odor. In trench No. 2, used in 1889, quicklime had been strewn upon each layer of organic refuse as it had been deposited and then covered with a layer of earth, but although traces of the lime and a discoloration of the soil could plainly be seen, yet the earth was entirely free from any unpleasant odor. The excavation was made about three feet deep. In trench No. 1, burial with the use of lime was commenced in May, 1890, and only partial decomposition was found to have occurred after the lapse of six or seven months. It was also found, as anticipated, that the destruction of the organic matter took place much more quickly near the surface that at a depth of three feet. The soil is a clayey loam, whose surface is from four to five feet above the level of the water in the outlet. From these examinations it appears that shallow trenches are better than deep ones, and after a period of three years the indication is that the same trench can be used again. The trenches were again examined in November, 1891, with the result that a decomposition of the organic wastes, similar to that already described, was observed.*

This Hemlock lake pail system is operated chiefly by steamboat for the summer season, only a few of the habitations being in use the balance of the year. In winter the necessary collections are made by wagon. The total cost of operation during the municipal year ending April 6, 1891, was as follows : †

Wages of steamboat engineer and crew and other labor involved in collecting excreta, garbage, etc., during open season	$1,413.05
Cost of collection by contract during winter	103.03
Cartage of coal and supplies for boat	21.00
Coal for steamboat	65.57
Copperas and chloride of lime	9.80
Asphaltum paint and oil	64.40
Moving pig-pens to other locations	15.00
Miscellaneous expenses and repairs	47.61
Total	$1,739.46

* 15th An. Rept. Ex. Bd. city of Rochester, for year ending April 6, 1891, p. 42. Also see 16th Rept., p. 32.

† From June 1, 1891, to October 1 of the same year, there were collected by steamboat 3,060 pails of excreta, 171 tubs of garbage, and 3½ pails of dead fish. From October 1, 1891, to April 1, 1892, the collections were made by wagon and row-boat, and amounted to 1,208 pails, the cost of this latter service being $6 per week.

During the year there was also expended in the way of permanent additions to plant and renewals, the sum of $352.18.

The approximate first cost of the permanent plant is given by the following statement, which is made in detail in order to show what the several items making up the total cost of such a plant really are:

(1)	Sanitary surveys and examinations, and law expenses attending inauguration of system in 1885	$265.40
(2)	Surveys for and preparation of plans of sanitary building, lake pier, tramway, and other permanent fixtures and superintendence of construction, estimated at	500.00
(3)	Frame building, elevated tank, and additions to same since original construction, including inside fittings, pump, etc.	850.22
(4)	Flat-bottom scow in use for first three years	149.77
(5)	Original road from lake to sanitary building	39.59
(6)	Original landing dock at lake	11.25
(7)	For permanent pier 400 feet long, and tramway 1,800 feet long	4,660.55
(8)	Tram-cars	57.50
(9)	Flat bottom steamboat with small row-boat	1,907.20
(10)	Remodelling about 100 privies for reception of pails	69.47
(11)	For metallic sanitary pails, transportation of same, etc	1,256.17
(12)	Miscellaneous, including land (partly estimated)	232.88
	Total approximate cost of permanent plant to April 6, 1891	$10,000.00*

The total cost of operation for six years is shown by the following statement:

For the municipal year ending April 5, 1886 †	$497.49†
" " " " " " 4, 1887	1,525.58
" " " " " " 2, 1888	1,461.53
" " " " " " 1, 1889	1,740.78
" " " " " " 7, 1890	3,912.09‡
" " " " " " 6, 1891	1,739.46
Total cost of operation for six years	$10,876.93

During the six years of operation which are here included, from 18,000 to 20,000 pails of night soil, garbage, and dead fish have been disposed of by this pail system.

The expense of doing this work, both in first cost and annual cost of operation, is evidently much greater than it would be for a similar performance in a town or city. The peculiar nature of the plant and the long distances covered may be taken as the main reasons for this.

* In this total of $10,000 is included the cost of all new metallic pails purchased to April 6, 1891. Some of these are properly chargeable to renewals, but by reason of the impossibility of determining from the accounts as kept just where renewal stops and legitimate increase of plant begins, all such expenses are grouped together in item (11). The plant may now be considered complete and fully adequate to perform the work required of it without further extension, and from this time on expenses of the sort under consideration may be properly charged to renewals.

† First year, not in operation for the whole season.

‡ The statement for this year contains a large amount of labor properly chargeable to other accounts which cannot now be separated. The expenses of operation proper probably did not exceed about $1,700.

The moving of the pails by boat, and the construction of a pier for facilitating such moving at all stages of the lake, is an imperative necessity due to the peculiar situation. The west side of the lake, on which is located a considerable number of the cottages, is absolutely inaccessible except by water; the cottagers themselves, even, going to their temporary homes by boat from the opposite side. As yet we have no pail system in a town with which to compare the figures as given for this exceptional case.

CHAPTER XXII.

THE FULLERTON AVENUE CONDUIT AND THE BRIDGEPORT PUMPING STATION, AT CHICAGO.

THE gradual increase in the pollution of the two branches of the Chicago river on account of receiving larger and larger amounts of sewage from year to year led in 1874 to the beginning of the construction of the Fullerton Avenue Conduit, which was designed especially for the relief of the North branch. The plan adopted included the construction of an open cut and tunnel conduit from the river to the lake, and the erection of machinery for operating a screw by which a current of water could be sent at will, either from the lake to the river, or from the river to the lake, as might be necessary at different stages of the lake to secure the most thorough flushing of the river.

THE FULLERTON AVENUE CONDUIT.

So far as the authors know, up to that time no similar plan for sewage disposal had been carried out anywhere, probably because just the conditions which seemed to necessitate this particular arrangement had not occurred in any other place. Since then a similar arrangement has been carried out at Milwaukee, and we may accordingly include a description of the Fullerton Avenue Conduit, and its pumping machinery, as involving on the whole a somewhat unique method of sewage disposal, at any rate so far as its mechanical features are concerned.*

Owing to the failure of the original contractors, and other causes of delay, the Fullerton Avenue Conduit was not completed ready for operation until January, 1880. The following description of its proportions and principal mechanical features as originally carried out, taken in conjunction with Figs. 31 and 32 will give a general idea of this work.†

The conduit is of brick, circular in section, 12 feet internal diameter, and 11,898 feet long, from the lake shaft to the North Branch of the

* For extended discussion of some of the engineering features of the Fullerton Avenue Conduit see a paper Fullerton Avenue Conduit, etc., by Lyman E. Cooley, C. E., in Eng. News, vol. iii., pp. 212, 220, 229 (July 1, 8, and 15, 1876). A paper descriptive of the Milwaukee plant was presented by Geo. H. Benzenberg, M. Am. Soc. C. E., before the International Engineering Congress at Chicago, in August, 1893. The paper will be published in Trans. Am. Soc. C. E.

† Abstracted from the 4th An. Rept. of the Dept. of Public Works, etc., of Chicago, for the year ending Dec. 31, 1879, pp. 70–75.

Chicago river. The bottom of the invert from the river to Racine avenue, a length of 4,270 feet, is level, and 13 feet below the city

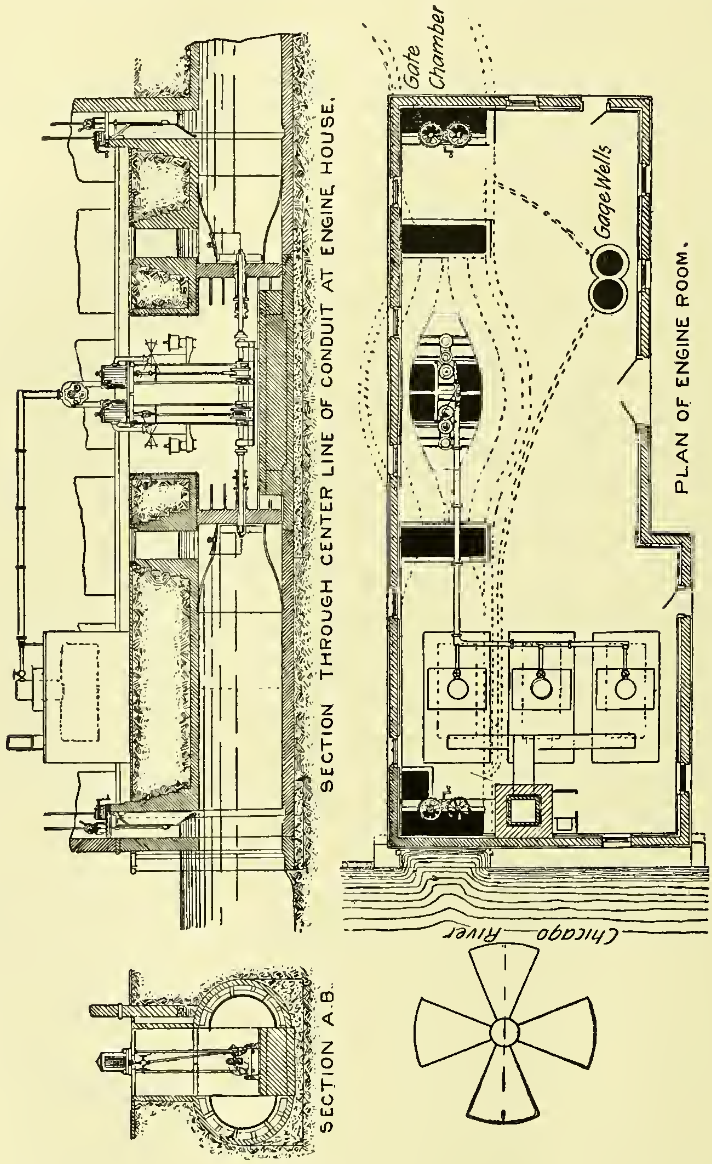


FIG. 31.—FULLERTON AVENUE CONDUIT PUMPING STATION, CHICAGO.

datum. East of Racine avenue there is a vertical reversed curve connecting the upper and lower grades of the conduit, which latter at this point is $27\frac{2}{3}$ feet below datum. The tunnel continues by a series of

descending grades to the lake-shore shaft, where the invert is 54½ feet below city datum. From the shore shaft to the lake discharge shaft, a distance of 1,000 feet, the conduit is level. From the North Branch to Racine avenue the work was in open cut, and from Racine avenue

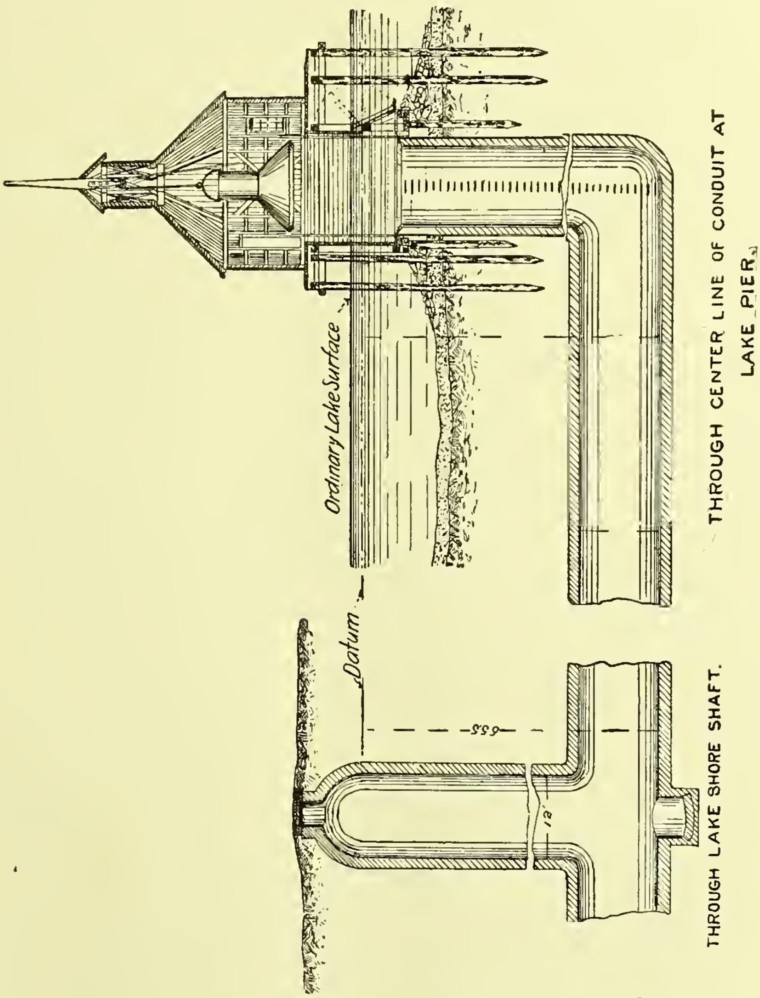


FIG. 32.—SECTIONS THROUGH FULLERTON AVENUE CONDUIT, CHICAGO.

eastward in tunnel, the grade followed the level of suitable ground for tunnelling.

The upper part of the lake shaft is a cast-iron cylinder, 1¼ inches thick, 14 feet 2½ inches outside diameter, and 24 feet long, cast in six sections of four feet each, and bolted together with internal flanges. The cylinder is lined with brick masonry, making it 12 feet internal

diameter. The part of the shaft below the cylinder is also 12 feet internal diameter.

The top of the cylinder is $4\frac{1}{2}$ feet below city datum, and located in a wooden chamber, 34×18 feet inside, with openings on the east side into the lake. These openings are fitted with gates, which are intended to be closed only when the cover is on the shaft, in order to prevent it being lifted or damaged by the violence of the waves. At this end the water may be shut off from the conduit by a conical cover of boiler plate, on the lower end of which is a strong flange, inclined at an angle of 45° with the horizon, and fitting on a similar flange, cast on the top of the shaft, with a packing of India rubber tubing between the two flanges, making a perfectly water-tight joint. The cover projects above the water, and is provided with an opening to allow access to the shaft.

The shaft is protected from the violence of the waves by a pier of pilework securely braced together, and filled at the ends to the level of the water with loose stones or riprap, and built so as to offer the least resistance to ice and storms ; on the pier and over the shaft is a frame house in which is fixed a winch for raising or lowering the cover of the shaft. The shafts at the lake shore, Larrabee street, and Sheffield avenue, are 12 feet internal diameter, being built of a size to afford suitable facilities for working during the construction of the conduit. At each street intersection are shafts of 6 feet internal diameter, with eyes or junctions formed in them at suitable depths to afford ready means to connect with the sewerage system if it is found desirable to do so.

These shafts are carried up to the level of the street, domed over, with openings on top for access, and covered with strong covers, and all provided with ladder irons. At the river end, where the machinery is located, the conduit is divided into two semicircular channels, which pass one on each side of a wrought-iron chamber. After passing the chamber the two channels are again united to form one channel, of the same size and section as the main conduit, which is continued to the outlet on the river. The outlet is protected by a heavy masonry dock wall, in which is fixed a screen of iron rods for the purpose of preventing floating debris from entering the tunnel and obstructing the screws when the current is from the river to the lake.

The water is forced through the conduit by means of two screws similar to those of an ordinary propeller, one fixed at each end of a horizontal shaft 40 feet in length, and placed in the centre line of the conduit. This shaft passes through a boat-shaped iron chamber, 10 feet in its greatest diameter, and secured to masonry foundations by 28 two-inch bolts. All joints in the chamber are calked and made water-tight. The motive power is two single-cylinder condensing en-

gines, with cylinders 20 inches diameter and 30 inches stroke, with side valves, cut-off motion, and reversing gear, in order to permit them to run either way. The engines are placed on top of the chamber at the level of the engine-house floor.

The driving-shaft is 8 inches in diameter and made in three sections. The engines are coupled to the middle or crank section by connecting-rods 16 feet long. This section also carries the eccentrics for working the valves and is supported on pillow-blocks bolted to the masonry foundations. The end sections are connected to the middle by couplings, which have a longitudinal play sufficient to prevent the thrust being communicated to the middle section. They are also provided with an adjustable device to prevent the thrust and wear from the screw coming upon the end post of the chamber.

The original screws were four-bladed, 6 feet 7 inches diameter, with a pitch of 8 feet. The back and forward edges of the blades were projected upon a plane parallel to the axis, and parallel one to another, and the blades as foreshortened in projection were made 12 inches in width, giving the total area of the four blades of each screw one-half of the total area of a complete turn of the helicoid. The original screws were, however, removed in 1882 and a set 8 feet in diameter substituted in their place.

There are three cylindrical boilers, 16 feet long and 66 inches diameter, with forty 5-inch longitudinal tubes in each boiler. Each boiler has 30 square feet of grate surface and 1,000 square feet of heating surface, and is connected with a brick chimney $3\frac{3}{4}$ feet square inside and 100 feet high. The boilers are designed to bear a constant pressure of 80 pounds per square inch above the atmosphere, although it is not intended to work them with more than 60 pounds pressure of steam.

The engines are designed to work at a uniform rate of 100 revolutions per minute, and required to make as many as 125 revolutions per minute without injury.

The portion of the conduit surrounding the shaft chamber and at each end of the same, a total length of 64 feet, is lined with a circular timber lining, funnel-shaped at the ends. At each end the lining is 12 feet inside diameter, from thence forward it is contracted in size, and at the screws it is only one inch more in diameter than the screws.

In designing the machinery there was some doubt as to the best size and form of the screw, there being no precedent of a propeller wheel used for forcing water in a confined channel, and the lining of the screw chamber was accordingly made somewhat of a temporary character, easily altered and adapted to any size and form of wheel which from experience might be found best and most economical to perform the required work.

To afford easy access to that part of the conduit where the screws are, two circular slide-gates are placed, one at each end of the engine-room, about 92 feet apart; these gates are 12 feet clear opening, made of boiler plate and faced with brass; in the centre of each gate is a supplementary gate 36 inches diameter, to relieve the pressure from the large gate when required. The gates are operated by worm gear placed in the engine room, and when closed the portion of the conduit between the gates can be pumped dry in a short time, so that the necessary repairs or alterations can be made in the screws.

In order to ascertain the head of water against the screws, two wells are built adjacent to each other, each connected with the conduit by a 4-inch pipe, one to the west of the shaft chamber and the other to the east of it.

The original cost of the Fullerton Avenue Conduit, including the pumping machinery, was about $565,000.

The Bridgeport Pumping Station.

In 1883 the present pumping plant at Bridgeport, which was designed to force a larger quantity of water than had previously been possible from the South Branch of the Chicago river into the Illinois and Michigan canal was completed ready for operation. This work, as leading to disposal of the sewage flowing into the South Branch, may be now described, reference also being had to Figs. 33 to 37, inclusive.*

The building is located across the old channel of the canal, about 265 feet west of the South river, as shown in Fig. 33. The influent channel, 60 feet wide, was dredged to a depth of 10 feet below city datum. Its sides are vertical and maintained by a timber dock built in the usual manner. The effluent channel was excavated to a depth of 6 feet below city datum, and the side slopes paved with stone. The position of the boiler and engine-houses in reference to the channels is so fully shown on the accompanying plan, Fig. 33, as to render description unnecessary. The machinery consists of four sets of centrifugal pumps, having a combined capacity of about 50,000 (nominally 60,000) cubic feet of water per minute, raised to a height of eight feet.†

Each set consists of two centrifugal pumps placed in a dry well below the surface of the water in the river, and driven direct by a vertical condensing compound engine, with high-pressure cylinder 18

* Abstracted from 7th An. Rept. of Chicago Bd. Pub. Works for year 1882.

† The enlargement of the pumping plant to a capacity of 100,000 cubic feet per minute has been begun since the above was written. The contract called for eight undulating pumps, each with a capacity of 12,500 cubic feet per minute, but was conditioned upon the success of the first two pumps, which were tested July 17, 1893. See Eng. News, vol. xxx., p. 70 (July 27, 1893), for results of tests, illustration and description of new pump, recent operation of old, and condition of the Chicago river in 1893.

inches diameter, both being 34 inches stroke. Surface condensation is effected by a series of pipe condensers placed in the current of

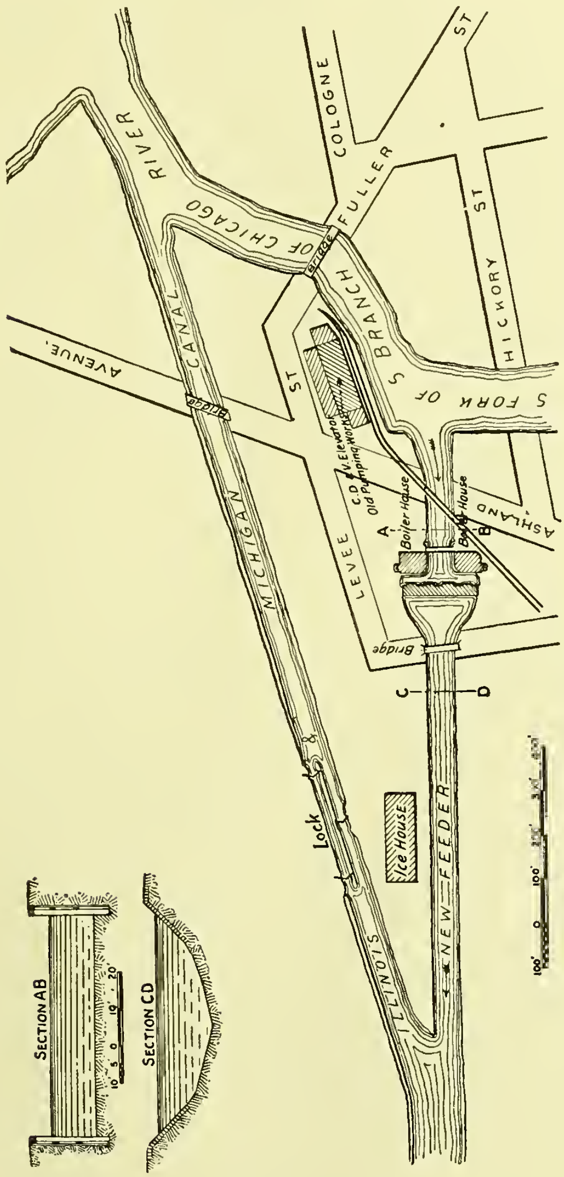


FIG. 33.—PLAN SHOWING LOCATION OF BRIDGEPORT CANAL PUMPING STATION, CHICAGO.

water in the influent channel, and so devised that each may be hoisted separately out of the water, and cleaned or repaired, and then replaced without emptying the channel or interfering with the operation of the

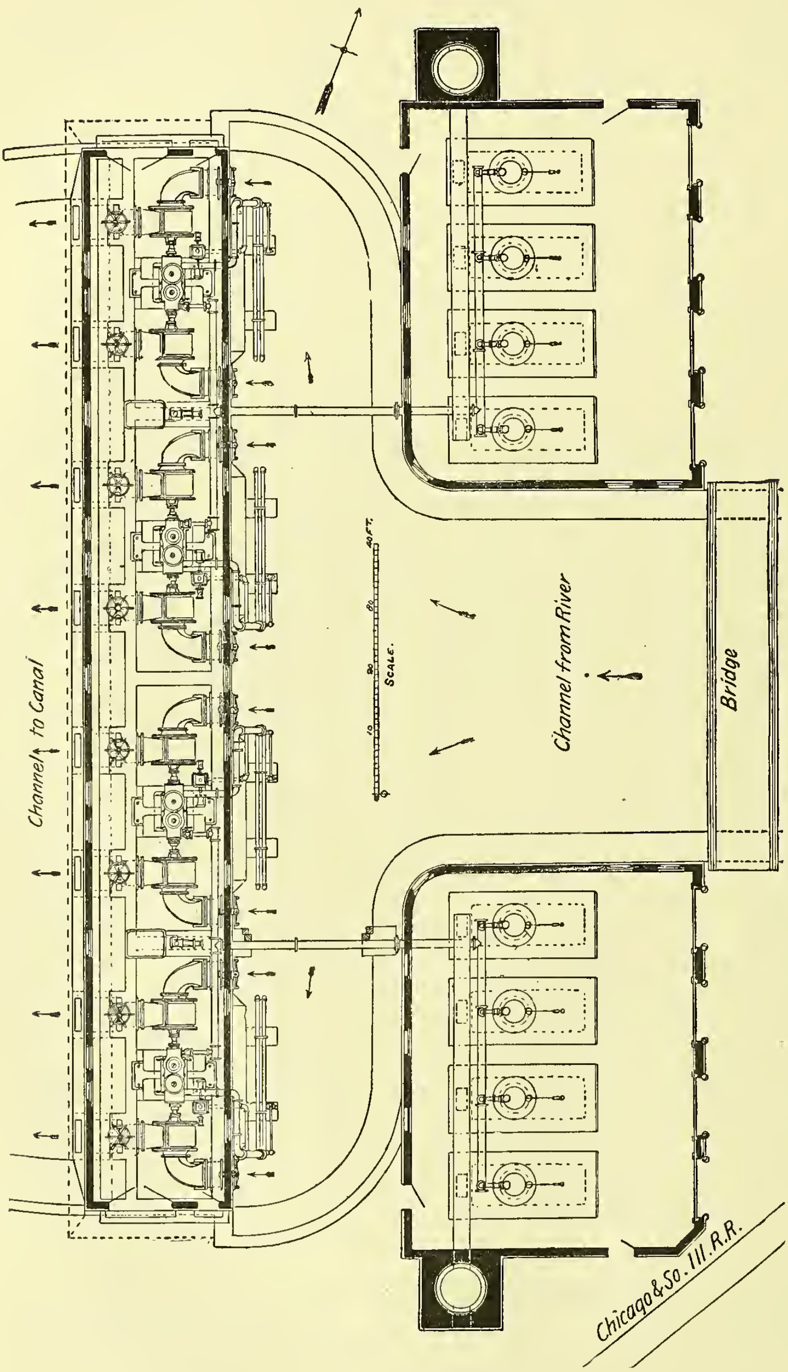


Fig. 34.—Plan of Bridgeport Pumping Station.

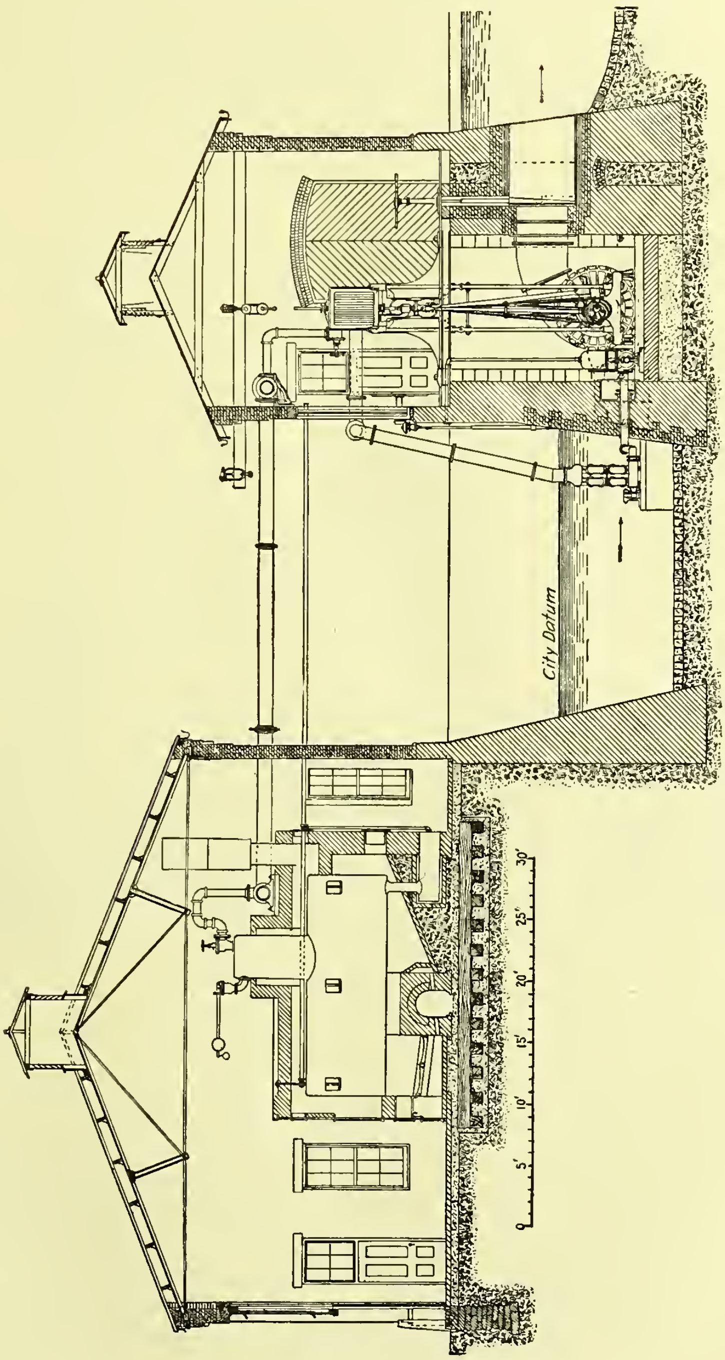


FIG. 35.—CROSS-SECTION OF BRIDGEPORT PUMPING STATION.

others. The air-pumps are independent, and located in the dry wells. The pump-wheels are cast iron, 6 feet diameter, of the form shown by the accompanying drawings. Each is furnished with separate supply and discharge pipes, which are $3\frac{1}{3}$ feet diameter at the pump, and increased gradually to $4\frac{1}{2}$ feet by $4\frac{1}{2}$ feet at the outlet. They are pro-

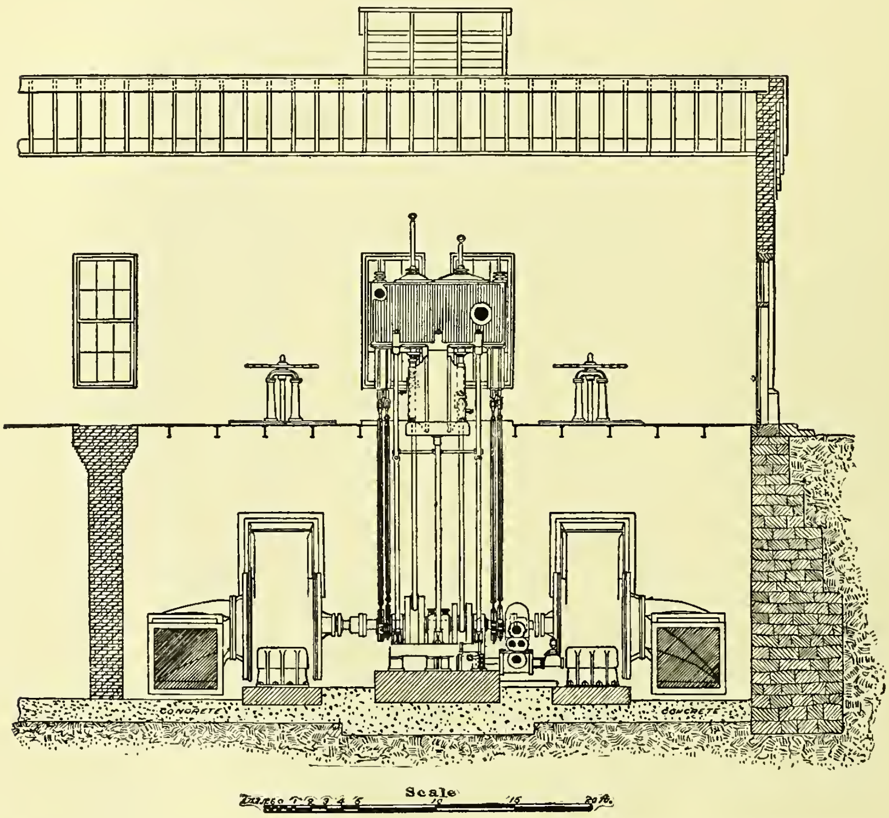


Fig. 36.—Longitudinal Section of One Set of Bridgeport Pumping Engines.

vided with gates to shut off the water, which are operated on the floor of the engine-room.

Each pump is coupled direct to the engine crank-shaft, which may be conveniently disconnected, if desired, by removing the coupling-bolts. The engines are adapted for running at high speed, and are provided with adjustable cut-off valves. All wearing surfaces are of steel, with boxes of phosphor-bronze.

There are eight horizontal return tubular boilers, each $6\frac{1}{2}$ feet in diameter, and 18 feet long, and containing 60 tubes, each $4\frac{1}{2}$ inches

diameter and 18 feet long. The boilers are designed to withstand a pressure of 80 pounds per square inch, and are provided with the usual gages and valves. Each set of boilers is connected with a 9-inch

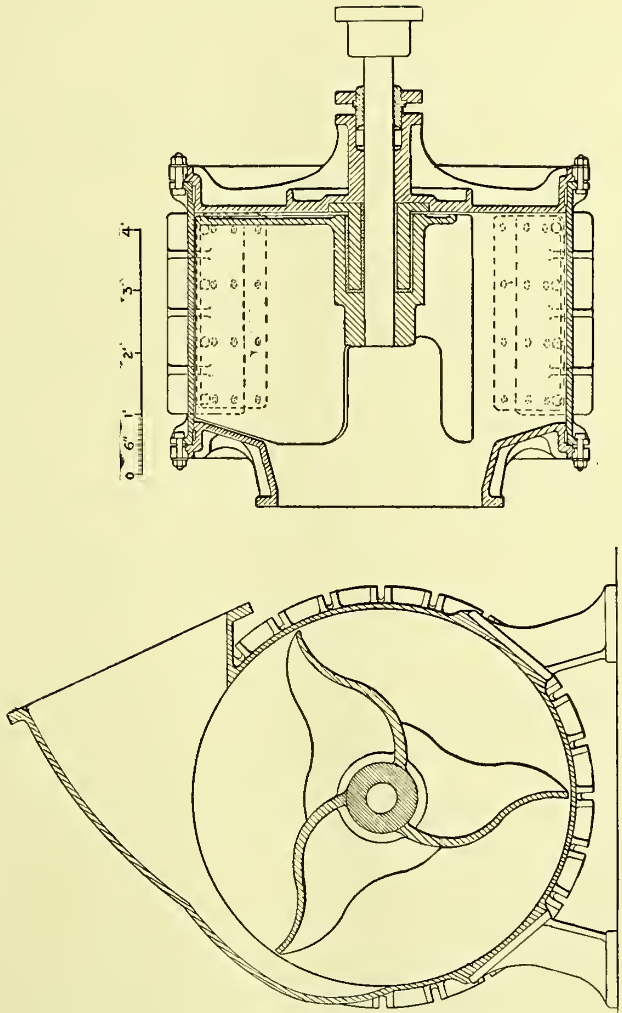


Fig 37.—Section of Centrifugal Pumps, Bridgeport.

steam-pipe in the engine-room, from which smaller branches lead to the different engines.

The water of condensation is delivered into boiler-iron tanks, and from there returned to the boilers by two steam feed-pumps, each having 8-inch steam and 5-inch water cylinder.

For the purpose of determining the capacity of the pumps, a mov-

able weir was constructed across the effluent channel near its junction with the canal, with four openings, each 10 feet wide, with knife edges.

To prevent the water returning into the river from the canal a timber lock was constructed in the canal a short distance east of the junction of the influent channel. The walls are of crib-work, built with 2x8 inch timbers, laid flat, one on top of the other, spiked together and filled with stone. The chamber is 240 feet long between gates, and 19 feet wide. The floor is formed of 10x12 sleepers, bedded in the ground and covered with two thicknesses of 2-inch plank. This floor extends beyond the chamber to the nose of the crib-work.

Outside of the lock are waste-gates, 38 feet wide, to be opened when the works are not running during flood-time, or when the works are not in operation from any cause, so as to leave as large a way as possible for the passage of water. The gates, sills, and quoins are of white-oak timber, framed together and sheeted with pine, and have sluice-valves in the bottom operated by levers and racks.

The total cost of these works was about $270,000.

CHAPTER XXIII.

CHEMICAL PRECIPITATION PLANTS AT CONEY ISLAND, ROUND LAKE, WHITE PLAINS, AND SHEEPSHEAD BAY, NEW YORK.

THE disposal plants at Coney Island, Round Lake, White Plains, and Sheepshead Bay, New York, all employ the same general system of purification and may therefore be described together. This process, in brief, consists of the automatic introduction of lime and perchloride of iron to sewage in precipitating tanks, the deodorization and disinfection of the sludge, or, if desired, of all the sewage, by chlorine, and the removal of the sewage from one compartment of the tanks to another and finally to the effluent pipe by means of siphons, the latter also effecting the change of level in the tanks which causes the automatic introduction of the precipitants in the desired quantities. The system was designed by J. J. Powers, C. E., Brooklyn, who holds patents on certain features.

CONEY ISLAND.

The first of the four plants to be put in operation was that at Coney Island, in 1887. This place is a well-known sea-side summer resort near New York and Brooklyn, the sanitary condition of which some ten years ago was deplorable.*

In 1884 the New York Legislature empowered the Board of Health of the town of Gravesend to construct sewerage and sewage disposal systems in any district of the town upon petition of a majority of the property-owners of the district affected. Since that date the Board of Health has built sewage purification plants for both the Coney Island and Sheepshead Bay districts, after designs by Mr. Powers. The plans for the Coney Island plant were submitted in a competition and were approved by Robert Van Buren, M. Am. Soc. C. E.

The Coney Island plant, being the first one constructed, is the simplest of the four, but is essentially like the others except in minor

*See results of an investigation by W. P. Gerhard, C. E., Eng. News, vol. xiv., pp. 1781–82 and 210–214 (Sept. 19 and Oct. 3, 1885). These articles describe the sewage disposal methods adopted prior to Sept., 1885, by the large hotels at Brighton and Manhattan beaches, some of which seem to have been the precursors of the Powers process as applied to town sewage.

details and comparative smallness of the tanks. Perchloride of iron was the only precipitant used until the fall of 1892, since which time lime has also been used.

A sketch plan and approximate longitudinal section of the plant are shown by Figs. 38 and 39. Two 24-inch trunk sewers join in a 30-inch pipe near the works, which branches to supply sewage to the two halves of the tanks. The sewage settles and is screened in the first tank, lime being used to increase the sedimentation since the fall of 1892. A T-overflow conveys the sewage into the next compartment, where perchloride of iron is added automatically. A siphon discharges

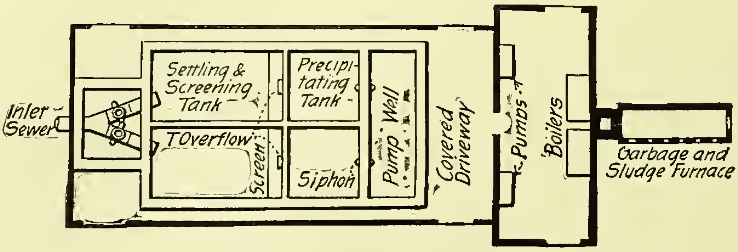


Fig. 38.—Sketch Plan.

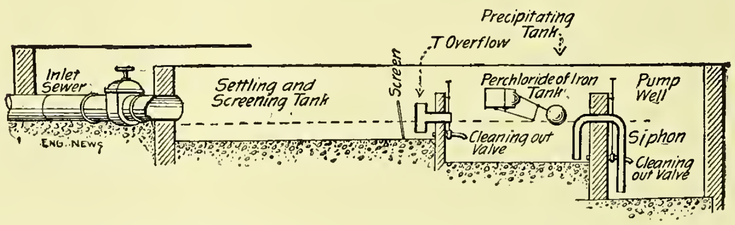


Fig. 39.—Longitudinal Section Through Tanks and Pump Well.

this compartment, when full, into the pump-well. The change in the level of sewage in this tank operates a float-valve to discharge the perchloride of iron from a tank provided for the purpose. The method employed to introduce the chlorine into the sludge is described further on.

The first year the works were operated the sludge was carried away by a scow, the works being close by Coney Island creek. For the last few years the sludge has been mixed with sawdust and burned in an Engle garbage crematory shown in plan at the end of the building, Fig. 38.

Two Davidson pumps lift the effluent a few feet and discharge it through a pipe into salt water.

The summer population and visitors at Coney Island probably ex-

ceed 100,000 for a few hours on some days. The census of June, 1890, showed a population of 3,313 in the incorporated village of Coney Island.*

Round Lake.

The second plant built under the Powers patents is located at Round Lake. It needs but brief description, since it is only an elaboration of the Coney Island plant with details changed to suit local requirements. William B. Landreth, M. Am. Soc. C.E., was the designing, and J. Leland Fitzgerald, M. Am. Soc. C.E., the constructing engineer, these two gentlemen having been associated at the time under the firm name of Landreth & Fitzgerald, of Schenectady, New York. Mr. Fitzgerald described the works in detail in Fire and Water for February 14, 1891. The following is slightly abbreviated from a condensation of the above paper, combined with later information, which appeared in *Engineering News* of October 20, 1892 :

Round Lake is a summer resort near Saratoga Springs which has developed from a camp-meeting ground with tents for shelter to a collection of cottages and other buildings which serve a permanent population of about 400 and a summer population averaging 1,500, perhaps, with 7,000 or more people on the grounds during some days. The cottages and property are owned by the Round Lake Association, of which J. D. Rogers is superintendent.

Water-works and a sewerage system were built in 1887, the sewers having been laid in the same trench as the water-mains. Money to pay for the water and sewer systems was raised by subscription and lot assessment.

A restricted amount of surface water is admitted to the sewers in the centre of the village only. The buildings are so close together that a single house drain serves from two to six buildings, thus reducing the total length of the sewers proper.

The only available water into which the sewage could be discharged was Round lake, close by which the buildings are located. Some form of purification was therefore necessary. Broad irrigation was out of the question, as a sufficient area accessible by gravity could not be secured. An area of three acres was chosen for downward intermittent filtration, the location being governed by distance from the residence section rather than by suitability for the purpose. The land needed grading and underdraining. As nothing of the sort was done except to lay a few lines of tile, purification was not effected and a nuisance arose. It was finally decided to put in a plant for chemical treatment and the process of Mr. Powers was adopted.

* A more detailed description of this plant is given in Eng. News, vol. xxviii., p. 368 (Oct. 20, 1892). Mr. Baker visited the disposal works shortly before the date just named and found them, apparently, in excellent condition.

A sectional plan of the purification works is shown by Fig. 40 and several vertical sections by Fig. 41.

The pit A, Fig. 40, in the first compartment, is designed to retain a large part of the sludge. The screens S detain all large objects which have not settled, there being a screen or stop at the surface to intercept floating matter and a mesh screen placed across the channel. The sewage passes into the siphon-chamber GB through the inverted trapped overflow O. The siphon SI removes the sewage automatically from GB to the long narrow chamber C, from which it overflows into D and again into L, from which the final siphon SI delivers it into the manhole N. From this manhole the effluent passes through a pipe to the lake, 700 or 800 feet distant.

The lime is admitted to the sewage, as it enters the first compartment, from the left end of the lime tank LI. The perchloride of iron is admitted to the sewage before it passes through the first siphon, being discharged from the measuring tank MT, which is connected with the storage tank CI. Both the lime and perchloride of iron are discharged automatically through feed-cocks worked by lever-floats. For the lime tank a spring tripped by a cam on the lever is used. The chlorine generators CH are in a semi-detached building at the left ventilated by louvres.

When the precipitating tank AEFGB is cleaned the liquid is first drawn off into the final settling tank through the valves shown in the plan, Fig. 40, after which the more fluid portion of the sludge in the pit A is, or may be, pumped into the other side for further treatment by means of the centrifugal hand-pump located at P, in compartment E. Provision seems to have been made, also, for pumping from the pits H and M by centrifugal hand-pumps. Such sludge as is not pumped from pit A has some absorbent mixed with it (charcoal-dust has been used some of the time) after which it is shovelled into an iron bucket, lifted by a differential hoist and finally conveyed to a cart by means of an overhead trolley.

Mr. Fitzgerald states that for the two seasons 1889 and 1890 it was unnecessary to remove the sludge from the pits H and M more than once or twice in the season ; but that it was necessary to remove the sludge from pit A every four days during the season ; that chemicals were not used in winter, sedimentation being sufficient for the actual population of only 400 ; that for the two years, the average cost of labor and repairs had been $200 per year, and of chemicals, $150.

In August, J. D. Rogers, superintendent, wrote that during the past season lime and perchloride of iron had been used, but that chlorine had not been used, because a cock could not be obtained that would " hold out against the corrosion of the chemicals more than a few weeks," after which it became dangerous. The plant had been run

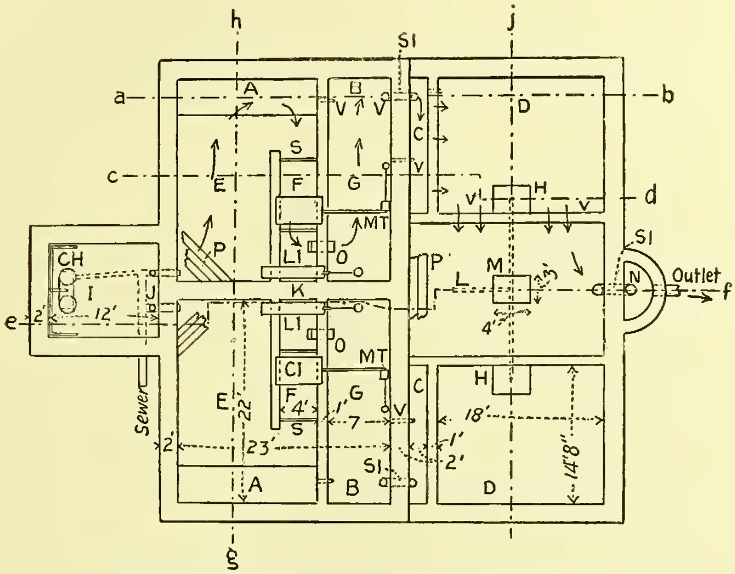


FIG. 40.—SECTIONAL PLAN OF ROUND LAKE WORKS.

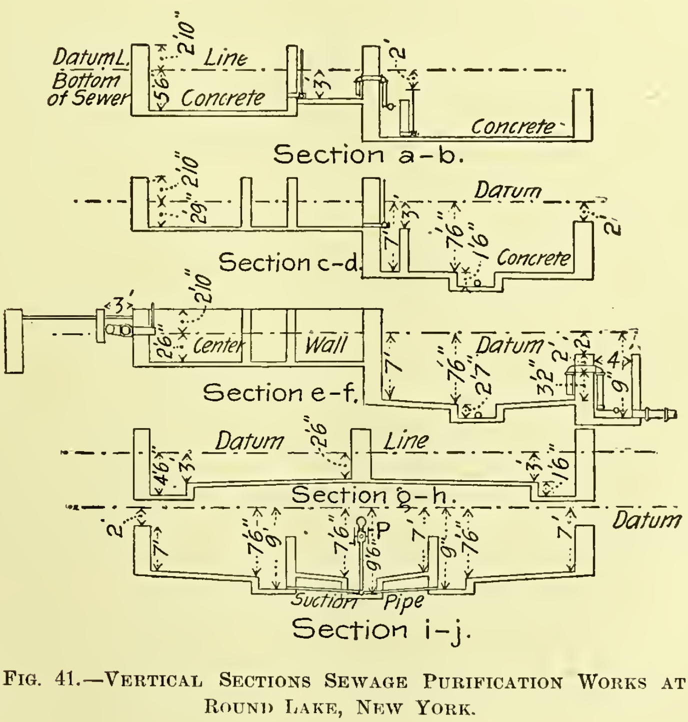


FIG. 41.—VERTICAL SECTIONS SEWAGE PURIFICATION WORKS AT ROUND LAKE, NEW YORK.

very well without the chlorine and the cost of its operation had thus been lessened. The cost of running the plant for 1892, Mr. Rogers stated, would be about $150, including chemicals and labor, while the resulting fertilizer would be worth about $30.

White Plains.

This plant and that at Sheepshead Bay were built at about the same time and differ more in engineering design and construction than in the details of the process, except that no final settlement of the effluent is provided at Sheepshead Bay. The process in its latest developments is described sufficiently in detail below for an understanding of its essential features:

White Plains is a suburb of New York, located on the New York and Harlem Railroad, 22 miles from the 42d street station. Its population by the census of 1890 was 4,042.

A public water supply was introduced in 1885. On Sept. 1, 1892, there were about 15 miles of water mains and 450 taps, the consumption of water being at the rate of about 350,000 gallons per day.

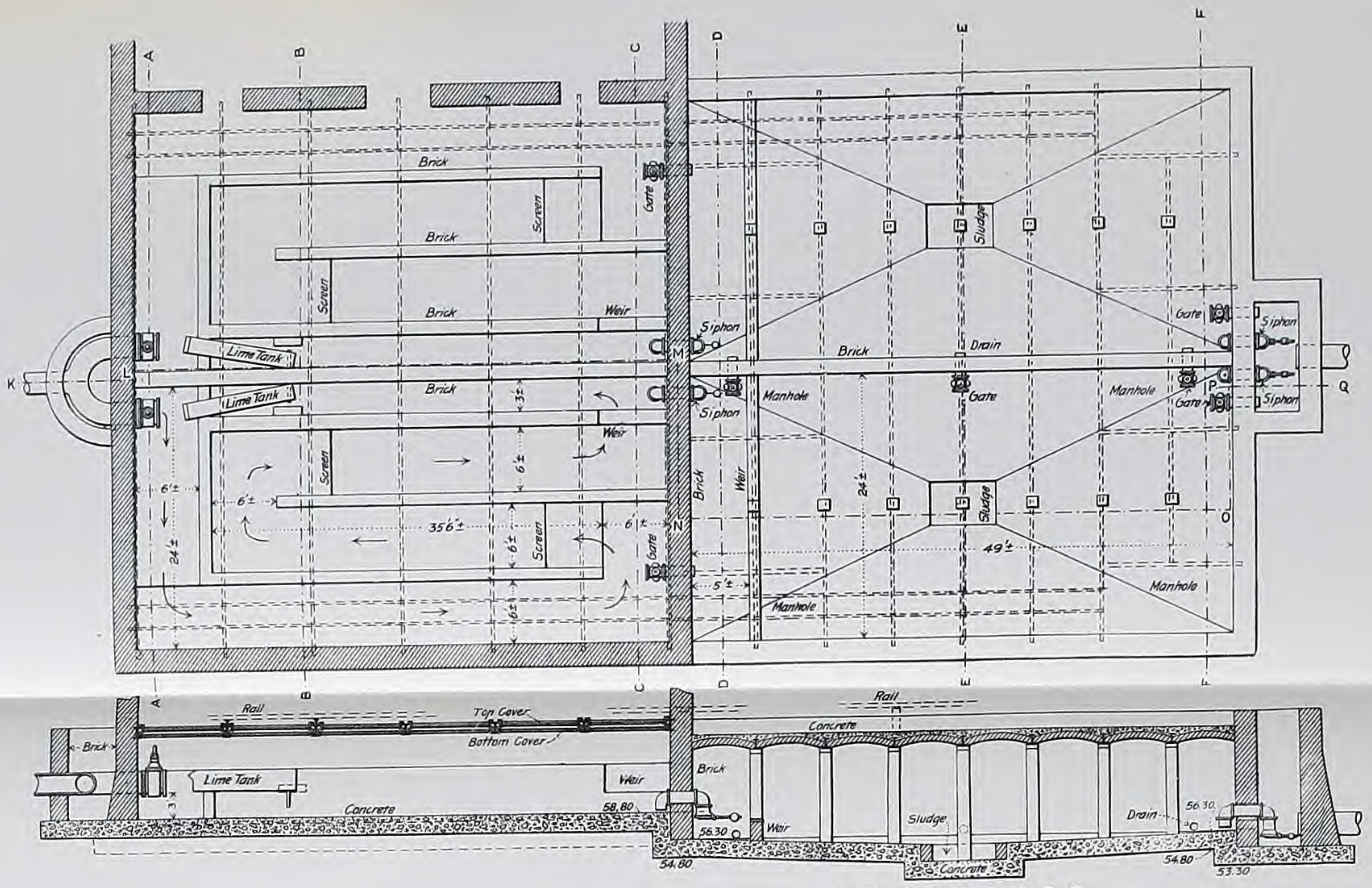
The sewerage system was put in use about March 1, 1892, it having been under construction for some time previously. Wm. B. Landreth, M. Am. Soc. C.E., Schenectady, New York, made the plans for the pipe system, which were approved in 1889 by the State Board of Health of New York. Wm. B. Rider, C.E., of South Norwalk, Connecticut, was made engineer of the work after construction started, and later E. D. Bolton, C.E., now of Brookline, Massachusetts, was made engineer, and under him the works were completed. Geo. R. Byrne, C.E., of Byrne & Darling, White Plains, was resident engineer in charge of construction under Mr. Bolton.

About ten miles of sewers are now in use. From April 1 to Sept. 16, 1892, 222 sewer connections were made. Prior to April 1 about 20 connections had been made.

The separate system is used, with about 50 flush tanks, mostly Rhodes-Williams with a few Van Vranken. There are about 100 manholes in the system, with perforated covers. As most of the roads or streets are of dirt these perforated covers admit much dirt to the sewers, increasing the amount of sludge at the purification works. In addition, the attendant in charge of the works states that when new connections are made with the sewers some house-owners take advantage of the opportunity to empty their cesspools.

About 2½ miles of underdrains were laid about on the same level as the sewers, as deemed necessary. These underdrains discharge into brooks where most convenient.

A 24-inch trunk sewer, about 7,000 feet long, leads to the purification



Section K, L, M, N, O, P, Q.

FIG. 1. PLAN AND LONGITUDINAL SECTION OF TANKS.

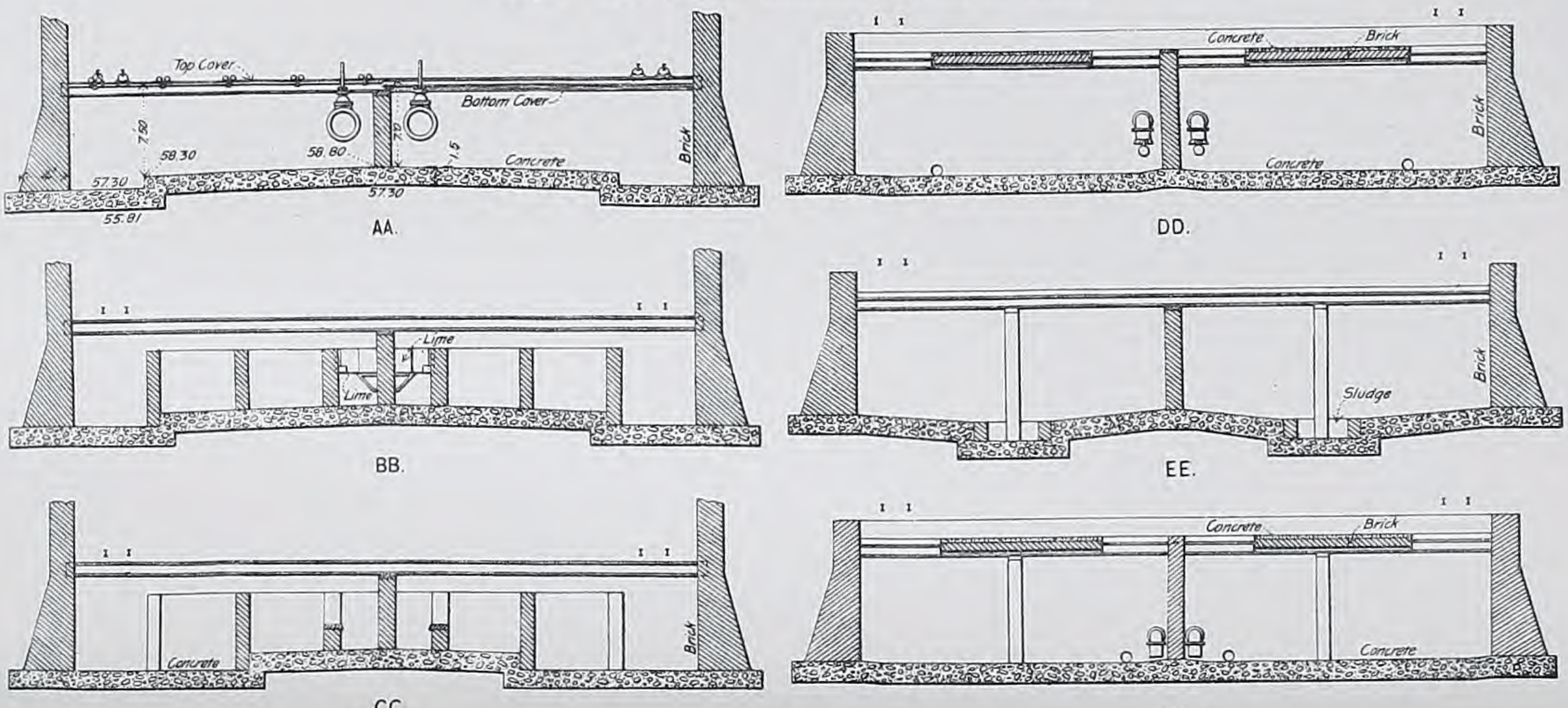


FIG. 2. CROSS-SECTIONS THROUGH TANKS.

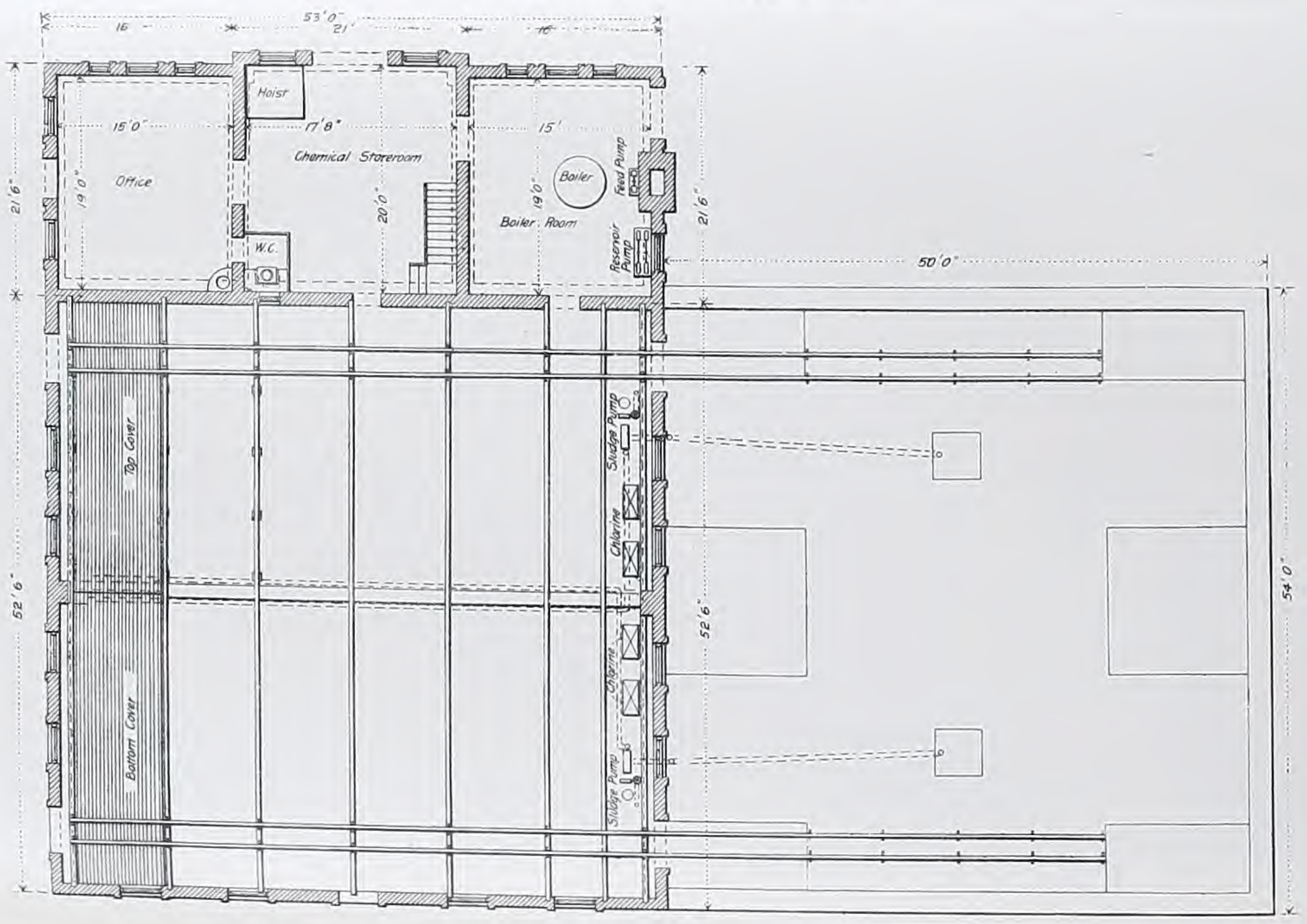


FIG. 3. FLOOR PLAN OF BUILDING.

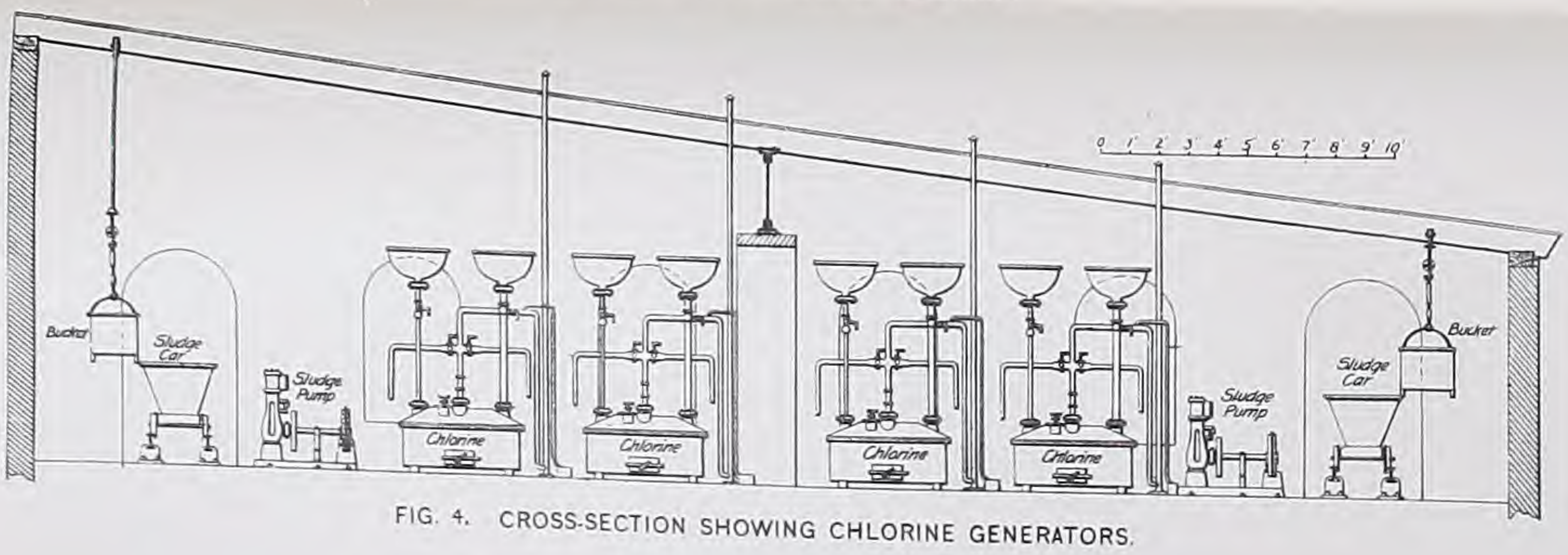


FIG. 4. CROSS-SECTION SHOWING CHLORINE GENERATORS.

PLATE III. PLANS AND SECTIONS OF CHEMICAL PRECIPITATION WORKS AT WHITE PLAINS, N. Y.

CHAS. HART & SONS, LITH., 36 VESEY ST., N. Y.

plant, which is located about 5,000 feet from the village on the west bank of the Bronx river close by the tracks of the New York and Harlem Railroad. This outlet pipe is of cast iron, except the last 600 or 700 feet, which is vitrified pipe. Mr. Byrne states that cast-iron pipe was probably used in order to exclude ground-water. The effluent passes from the purification works through about 3,000 feet of 24-inch vitrified pipe, laid parallel to the Bronx river, into which it finally discharges just below a mill-dam.

The main sewer from the village terminates in the well at the end of the building, shown in the plan, Plate III., Fig. 1. From this well the sewage may be turned into either set of tanks through the gates provided for the purpose.

As the first compartment of the tank is deeper than the others, much of the solid matter settles and is retained in it, going to the bottom by its own weight. The chemicals deposit more of the sludge as the sewage flows slowly on. A sludge-pit is provided in the centre of each final settling tank, as shown in Plate III.

The sludge from the sludge-pits and from the first compartment of the precipitation tanks may be lifted by the 4-inch centrifugal pumps through the piping shown in the plan and section, Plate III., and discharged into the opposite side for further treatment. The "primers" of the pumps are charged through 1-inch galvanized iron pipe from the force-main described above. The pumps are driven by engines supplied with steam from the boiler-room. The sludge can be removed finally by means of the bucket, car, and tramway shown in the cross-section, in Plate III., Fig. 4, the tramway being shown extending the whole length of the tanks in plan in Plate III., Fig. 3. The buckets have a capacity of $\frac{1}{4}$ ton, are of steel, self-dumping, and are raised by differential one-ton hoisting blocks and tackle, which run on an overhead single-rail tramway of one ton capacity.

The two dump cars are of $\frac{1}{4}$-inch boiler iron, one ton capacity. The tramway consists of 60-pound rails, two feet apart, clamped to the top of iron beams.

Before the sludge is removed from the tanks it is rendered less liquid and more easily handled by the addition of "German bog," said to come off the top of peat-beds. This bog comes in bales $2 \times 2\frac{1}{2} \times 3\frac{1}{2}$ feet and is a good absorbent.

All the sludge which had been removed from the tanks from the time the plant was put in operation until Sept. 2, 1892, was outside the building in a pile on that date. Some of it was colored brown by the peat, some pink, presumably by the iron, but much of it had the appearance of ordinary lime and sand mortar, due to the lime used as a precipitant and to the further fact that much dirt is admitted to the sewers through the perforated manhole covers, as stated above.

This large heap of sludge was perfectly free from odor, quite as inoffensive as a pile of mortar. Neither was there the slightest offensive odor anywhere about the works.

Thus far the sludge has been removed from the tanks and the chlorine used about once a month. The tanks may be washed perfectly clean by the use of water from a small reservoir on the hill or by direct pressure from a small duplex pump provided to fill the reservoir. This pump also affords fire protection for the building. The pump has 10-inch steam and 6-inch water cylinders, with 10-inch stroke. A 6-inch suction-pipe extends to the river, only a few feet distant. A 4-inch force-main extends from the pump to the reservoir on a hill near by, at a sufficient elevation to give a pressure of 47 pounds at the works. From the force-main a 2-inch galvanized iron pipe extends through the building and connects by means of 1-inch cast-iron pipe with the chlorine generators and tanks. Connections are also made with all the plumbing where water is needed. Linen hose, 200 feet in length, is provided for washing the tanks and for fire use.

The reservoir is of stone, cemented, $20 \times 10 \times 5$ feet, and, according to the specifications, covered with a building and connected by an electric indicator with the pump-room.

The settling chambers inside the building have rolling covers, the wheels running on I-beams, the wheels of one set of covers running on the upper and of another on the lower flange of the beam, so that the covers of one side may be rolled over or beneath those of the other.

The final settling tanks are covered with 8-inch brick arches supported by 90-pound I-beams resting on 12-inch brick piers. Openings 6 feet long and 12 feet wide, with sliding covers, are provided in each corner of the covering in these tanks.

The bottoms of all the tanks are composed of 18 inches of Portland cement concrete. The specifications state that all walls and piers to the height of the cross-walls must be laid in Portland cement mortar and plastered with the same where brick is used; also that the entire inner surface of the tanks must be covered with two coats of asphalt paint up to the coping. Provision has been made for heating the building, including the settling tanks, by steam.

There are two lime tanks, as shown in the plan and longitudinal section, Plate III., Fig. 1, each of riveted wrought iron, $1\frac{1}{2} \times 2 \times 10$ feet. There are also two 2,000-gallon riveted $\frac{1}{2}$-inch wrought-iron tanks for holding the perchloride of iron.

A hand hoist or elevator is provided in the chemical storage room, shown in the plan on Plate III., Fig. 3, for lifting the chemicals to the mixing tray of the chlorine generators and for lifting materials for storage in the second story.

The screens for stopping the large particles in the sewage as it passes through the tanks are shown in detail by Fig. 42. There are two of these screens for each set of tanks, located as shown by Plate III. They are made of $\frac{1}{8}$-inch wire, 1-inch mesh, swinging as shown in the illustration, to facilitate cleaning.

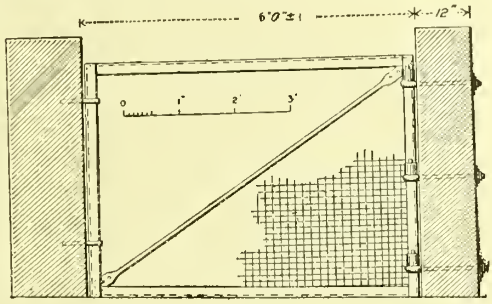


Fig. 42.—Hinged Screen in Sewage Tank at White Plains, New York.

In order that the chemicals used as precipitants may be admitted to the sewage automatically and in fixed proportion, the mechanism shown in Fig. 43 is employed for the lime and that shown in Fig. 44 for the perchloride of iron. Each of these devices depends for its action upon the varying levels of the sewage in a tank which contains a float connected by a lever with a cock, all so arranged, as described below, that the chemicals will be discharged in quantities and at intervals as desired.

Both Figs. 43 and 44 are designed to illustrate the principles upon which the mechanisms work, and not to show their exact arrangement at White Plains, although they do very nearly show the latter.

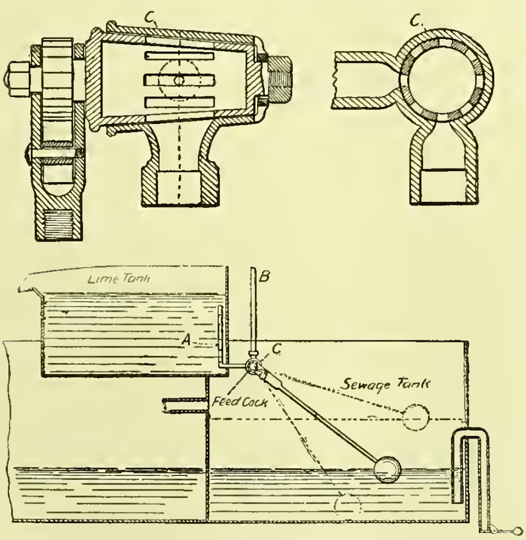


Fig 43.—Automatic Feed-cock from Lime Tank, White Plains, New York.

The lime is slacked in the lime tank, Fig. 43. Water is added to make a milk of lime, which is fed into the sewage over the lip of the lime tank. Water is admitted to the lime tank through the pipe A, which is supplied from an elevated tank on a hill through the pipe B and the feed-cock. The water tank gives a pressure of 47 pounds per square inch in the building. The pipe B is perforated at different levels, to cause the water to be discharged horizontally in order to stir up the lime, much of which would otherwise remain at the bottom of the tank.

The pipes A and B connect with the casing of the cock C, as shown in the two enlarged sections. The cock is inserted in this casing and is provided with longitudinal slots at regular intervals on its circumference, which are so arranged that whenever one of these slots opens against the contracted end of the pipe A another will open against the pipe B and vice versa.

The float is connected with the plug in such a way, that when it rises the cock is not turned, but when it falls a pawl engages with a ratchet and turns the cock so when the float is half way down the slots come opposite each pipe, and water is discharged into the lime tank and lime carried over the lip into the sewage. If the feed-cock

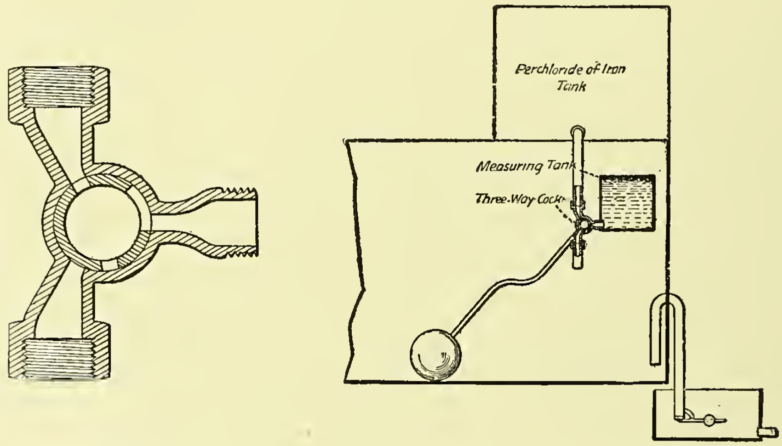


Fig. 44.—Automatic Three-way Cock for Perchloride of Iron Tank.

was opened with the rise of the sewage it is obvious that the slower the flow of sewage the greater would be the discharge of lime.

The device for admitting the perchloride of iron, Fig. 44, is slightly different, in that it is designed to measure this chemical accurately and to draw it from a storage tank of considerable size. To do this the storage tank is connected through a three-way cock with a small measuring tank placed on a lower level. The port of the cock which connects directly with the measuring tank is larger than the others and is always open. The third port connects, when in the proper position, with a pipe having its lower end over the sewage tank. The cock is turned automatically by the rise of the sewage so that the measuring tank is always emptied when or just before the float and the sewage are at their highest level and at no other time. The sewage is at its highest level just before it is siphoned from the chamber to the large final settling tank shown on Plate III.

In preparing the perchloride of iron for use, the storage tank is first

filled about half full of water, the desired amount of the chemical added and then the tank filled full. This method is followed to prevent injury to the valve. A 60 per cent. perchloride of iron is used, and two grains per gallon is considered a fair amount for ordinary sewage. The perchloride of iron is bought from Martin Kalbfleisch's Sons Co., New York, for 3½ cents per pound, or about $4.75 per carboy.

In passing from a consideration of the use of chemicals, attention may be called to the fact that the lime is admitted intermittently to sewage which has a continuous flow, and therefore some sewage may pass the series of chambers of the first tank to the weir over which the sewage flows to the first siphon chamber without receiving any direct addition of lime. Such sewage would have little or no precipitation to this point, but it would have sedimentation owing to the slow rate of flow. Since lime is discharged each time the first siphon works, every discharge of sewage into the final settling tank will contain lime, the only question being whether it is well mixed with the sewage. It would seem preferable to dischage the lime into the sewage continuously, or nearly so. This might be effected by arranging the float and feed-cock, Fig. 43, so that the water would be discharged into the tank with every few inches rise of the float, still maintaining a fixed relation between the lime and sewage. Or, better yet, a constant flow of lime might be maintained and the quantity varied to correspond with the volume of sewage by slowly passing the latter through a rectangular trough containing a lever-float which, rising and falling with the volume of sewage, would regulate the flow of lime through a feed-cock. The advantages of having the lime thoroughly mixed with the sewage the moment the latter reaches the first tank are obvious.

The chlorine for deodorizing the sludge, or for treating the total volume of sewage if desired, is made from common salt, black oxide of manganese, and sulphuric acid. The salt and black oxide of manganese are mixed, 1 to 1, in a tray above the chlorine generators, and washed down into the generator with 2½ parts of water. The cocks being turned to allow the chlorine to pass through the pipes and into the sewage tanks, sulphuric acid is then slowly admitted to the tanks and the chlorine generated. Acid should be admitted only in sufficient quantity to develop a pressure of 2 pounds, the pressure being indicated by a gage. A safety water-column and safety-gage are provided to keep the pressure down to 5 pounds, the blow-off pipe from the safety-gage extending up through the roof of the building. In addition the covers of the tanks being treated should all be tightly closed, and it is well to have the windows and door open. As inhalation of any amount of chlorine would be injurious to the nostrils, trachea, and lungs, the precautionary measures mentioned are advised on the printed directions for the generation and use of the chlorine and the

safety-gage is made a part of the plant. In practice, however, no trouble with the chlorine is experienced. It is obvious that since the chlorine is used to disinfect sludge or sewage it will be admitted to the tanks only when the perforated pipes are submerged, and if the chlorine should pass up through the sludge it would at once make the fact known, whereupon the acid could be turned off from the generators. In practice it seems probable that a deficiency rather than an excess of chlorine will find its way to the tanks.

The capacity of the final settling tank is about 27,500 gallons and of the small siphon tank or chamber which empties into it about 2,000 gallons, allowing for the sewage which flows into the latter while it is discharging. The sewage travels about 150 feet in the first or precipitating tank and 50 feet in the final settling tank, making 200 feet in all.

There were, early in September, about 450 taps connected with the water-works and about 250 sewer connections, which, being taken to yield as much sewage as the consumption of water per tap, 780 gallons, would give 195,000 gallons per day of natural discharge into the sewers. If the above figures are all approximately correct only a small amount of ground-water now finds its way into the sewers. When the plant had been in operation only a month, however, it is said that the daily flow through the tanks was 266,000 gallons. At that time there were but few sewer connections and the greater part of the flow must have been ground-water. The tanks are sunk in the old bed of the Bronx river, the river having been turned when the New York and Harlem Railroad was built, and at first there may have been some seepage into the tanks.

The amount of sewage treated at White Plains in September, 1892, was said to vary from some 200,000 gallons or under per day to about 300,000 gallons, or less, for which about one barrel of lime and one carboy, 10 to 12 gallons, of perchloride of iron was being used.

To operate the plant an engineer and a laborer are required during the day and a watchman at night. About one ton of coal a week is consumed in generating steam. The coal costs $6 per ton, delivered.

The contract price for the purification plant alone, without allowance for superintending construction, was $50,049. This was increased about $3,000 by errors in grade which necessitated the lowering of the foundations, but should not be charged to the cost of purification.

No analyses of the sewage after purification have been made, to the authors' knowledge, and as the plant has been in operation but a short time little can be said regarding the results obtained. At the plant nothing objectionable could be seen or smelled and everything seemed to be in good shape.

At the outlet into the river the effluent was somewhat clouded, which

might have been due, in part at least, to the use of lime. For several hundred feet down the river some of the finer particles of sewage were deposited in shallow water having little motion. In places these deposits were 3 to 4 inches deep, but they gave off little or no odor upon being stirred. The deposits may have been the result of improper management of the plant, especially too infrequent cleanings, which, as has already been stated, have thus far taken place but once a month. It may be that the lime does not become thoroughly mixed with the sewage, for the reasons mentioned above, in which case imperfect precipitation might be expected. In this connection it may be again stated that in constructing and operating sewage purification plants the controlling factor is the degree of purification desired. This decided, the next question is how to obtain it at the least possible expense.* The large and apparently inoffensive pile of sludge outside the purification building at White Plains witnesses that a great amount of pollution has been excluded from the Bronx river and rendered harmless. The deposits of sewage in the river gave no offence, even when stirred, and it is possible that the chlorine treatment had to a large extent rendered the deposits unobjectionable so far as decomposition is concerned.†

Sheepshead Bay.

The permanent population at Sheepshead Bay is probably less than 3,000, but its floating and summer population is much larger. Like Coney Island it is in the town of Gravesend and its works were built under the same board of health. Horace Loomis, M. Am. Soc. C.E., was consulting engineer for the system. The following condensed

* Throwing out of consideration the degree of purification effected, the following approximate estimate of the daily expense at White Plains may be given:

1 carboy of perchloride of iron	$4.75
1 barrel of lime	.75
Coal	.90
Engineer	2.25
Laborer and watchman, each, $1.50	3.00
Common salt, black oxide of manganese and sulphuric acid	.50
Oil and waste	.30
Miscellaneous	.50
	$12.95

Assuming that the present average daily quantity of sewage treated is 250,000 gallons, and that the daily expense of treating this amount is $12, the cost per 1,000,000 gallons would be $48. Undoubtedly when the town is fully sewered and the daily flow has become from 400,000 to 500,000 gallons, the cost will be somewhat less.

† Condensed from Eng. News, vol. xxviii., pp. 284–5 and pp. 314–15 (Sept. 22d and Oct. 6, 1892). In Eng. News of Oct. 6 may be found an account of the theoretical action of the lime and perchloride of iron upon the sewage, extracted from a pamphlet entitled Treatment of Sewage by Chlorine, Precipitation and Sedimentation, by J. H. Raymond, M.D., Professor of Physiology and Sanitary Science, Long Island College Hospital.

description, in connection with the preceding part of this chapter, will give a fair idea of the purification plant.*

The sewerage system was begun in 1891, and the purification plant was put in operation in 1892. The separate system is used. Water mains were laid by the town in the trenches with the sewers, there being about 13 miles of sewers and 15 miles of water mains.

Although the same process is used at Sheepshead Bay as at White Plains, the details of construction are in some respects quite different, which is largely caused by the circular plan of the works and the fact that it was necessary to construct it on a pile foundation. The village is very flat and the surface of the ground is near the water-line of the bay. The purification plant is located on marsh land subject to the tide flooding near an inlet or creek.

The 24-inch, egg-shaped cement outlet sewer from the village cuts across the marsh, turns and enters the building from the water side beneath the effluent pipe to the creek. The low levels and flat grades necessitate a deep receiving well from which the sewage is pumped to the tanks.

The lime is discharged into the sewage while the latter is in the pump well, after which the sewage is pumped into the tanks. There are no final settling tanks. The perchloride of iron is discharged into the chamber, from which the sewage is siphoned to the effluent chamber and pipe.

A 6-inch centrifugal pump, driven by steam, and having a 6-foot lift, was provided for handling the sludge, but it is not used. Sawdust is now mixed with sludge as an absorbent, after which it is shovelled into buckets, hoisted from the tanks, and pushed out in tram-cars as at White Plains. The sludge is used to fill in about the building, and was wholly inoffensive when the writer was at Sheepshead Bay, Sept. 12, 1892, as was everything else about the plant. The whole building is heated by steam and the village water supply is extended to the plant.

The effluent, as at White Plains, was slightly clouded. This seems to be admissible here, as does the omission of the final settling tank, for the effluent goes into a considerable creek of salt water. It is doubtful, however, whether the use of perchloride of iron at or near the time of siphoning is of especial advantage without the final settling tanks.

* For full details and illustrations, see Eng. News, vol. xxviii., pp. 308–9 (Sept. 29, 1892).

CHAPTER XXIV.

CHEMICAL PRECIPITATION AND FILTRATION AT EAST ORANGE, NEW JERSEY.

The town of East Orange, New Jersey, is situated immediately to the west of the city of Newark, and further bounded by the towns of South Orange, Orange, and Bloomfield, south, west, and north, respectively, as is shown in Fig. 45. The area is 2,400 acres, with a population in 1890 of 13,282. The topography is of a simple character, consisting of a nearly level plateau in the southern part, from which near the central part break four parallel valleys with drainage trending to the north. Within the limits of East Orange are three ridges, or low ranges of hills, which also run nearly north and south, and separate the valleys. The valleys are somewhat undesirable for residence by reason of greater dampness of the soil than is found on the ridges, which are generally dry and underlaid by the new red sandstone formation ; and until recently the bulk of the building in the northern part was on the ridges, the drainage from the better class of houses mostly passing into cesspools on the lower lands. Many of these had become very offensive, and considerable areas of soil were rapidly approaching complete saturation.

The increase of this unsatisfactory condition led the citizens of East Orange, as early as 1881, to take under consideration improved methods for disposing of domestic wastes, but it was not until the latter part of the year 1883 that a definite project was formulated. In that year, the matter of sewerage was taken actively in hand by the Town Improvement Society of East Orange, and a committee on sewerage and drainage, consisting of Messrs. J. C. Bayles, M. Am. Soc. M.E., Alfred P. Boller, M. Am. Soc. C.E., and E. Fortmeyer, Esq., appointed. At the meeting of the Improvement Society, held October 4, 1883, the committee reported that as a preliminary step toward securing a system of sewerage and sewage disposal they had requested J. J. R. Croes, M. Am. Soc. C.E., to prepare a plan for the complete sewerage of the town, with an approximate estimate of cost, together with suggestions as to the best method of sewage disposal.

Mr. Croes' report was in substance, that inasmuch as East Orange is entirely surrounded by other densely populated areas, which further cut it off from access to any large stream or to tide-water, if the waste

products were to be disposed of or purified within the township limits, it would be desirable to diminish their volume as much as practicable. Therefore the sewerage system should be chiefly confined to carrying house wastes. If in any case it were to be deemed desirable to carry roof water in the sewers it should be held back in cisterns and only allowed to empty gradually into the sewers. His plans provided,

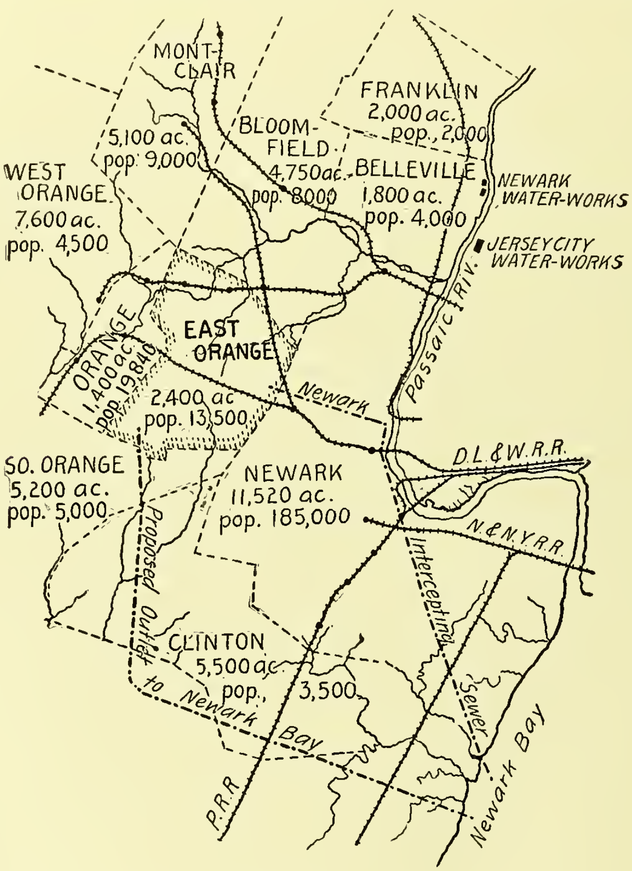


Fig. 45.—Map of East Orange, New Jersey, and Vicinity.

therefore, for carrying only a maximum of one-half cubic foot per minute for every 100 feet of street with the sewers running half full. The entire system would comprise 40 miles of sewers, 26 miles of which were to be of six-inch diameter with main outfall of an elliptical section 28 by 42 inches, computed to flow two-thirds full at the time of maximum flow. The main outfall sewer would be extended to the north-east corner of the town, where a suitable location for disposal

works could be found, near a tributary of the Second river, a stream emptying into the Passaic at the northern boundary of Newark.

The method of disposal recommended by Mr. Croes, was to first filter the sewage through a Farquhar-Oldham filter, the sewage having been treated with perchloride of iron before filtration; the filtering material, consisting of sawdust, was to be used, after filtration, as fuel under the boilers required for the pumping plant which would force the sewage through the filter. The effluent from the filter was to be further purified by passing through soil before reaching the stream.

The plan actually submitted provided for only one disposal station, although as an alternative plan the question was considered whether two stations on opposite sides of the town would not be preferable, thus avoiding a long and expensive deep sewer, which would otherwise be necessary for conveying the sewage from the southern district to the northern disposal ground. The cost of the whole system was estimated at $330,000. The Town Improvement Society's committee on sewerage and drainage indorsed Mr. Croes' recommendation as to the system of sewers, but advised, in their report of April, 1884, further deliberation in regard to the method of disposal, as recent legislation had considerably enlarged the authority of the New Jersey townships in the matter of acquiring rights to drain through other towns and municipalities. Under an act passed by the Legislature a short time previously, any township in the State having a population of not less than 2,000 to the square mile, and a public water supply, may construct a system of sewerage or drainage, or both; may have plans and estimates made; may build sewers in any part of any township; may, if necessary, appropriate any lands required by due process of condemnation; may build, if the township authorities shall deem it advisable, a main outfall sewer to tide-water, and for this purpose may pass through territory situated within the bounds of any other municipal corporation; may enter into contract with the authorities of any city whose territory adjoins that of the township, for the privilege of connecting the sewers of the township with those of the municipality; may purchase land and erect suitable buildings for the purpose of properly deodorizing, utilizing, or otherwise disposing of sewage; may apply to the circuit court of the county in which the town is situated for an appointment of commissioners to condemn any required lands; may borrow money, from time to time, to pay for public works, and secure the payment of the same by issuing bonds at a rate not exceeding six per cent. annual interest, and to an amount not exceeding ten per cent. of the assessed valuation of the property of the township, the legal voters at their annual meeting to decide the sum to be expended during the current year. The Act also provides for the payment of principal and interest of the bonds, and directs the town

assessor to levy assessments each year while the debt is unpaid, in a sum equal to the principal and interest which will fall due during that year.

In September, 1884, the township authorities directed Mr. Croes to prepare plans and estimates of the cost of conveying the town sewage to tide-water in Newark bay, below the city of Newark. Later on he was further directed to prepare additional estimates for disposal within the township limits. The plans and estimates submitted by Mr. Croes, in accordance with these instructions, showed that the construction of a sewerage system, sufficient for immediate purposes, would cost about $77,000. If the sewage were taken to Newark bay, the necessary outfall sewer, shown on the map, Fig. 45, would cost $154,000, while if chemical treatment, supplemented by filtration through land within the township limits, were adopted, the cost would be $76,000. With disposal to Newark bay the cost of completely sewering the town, including sewerage system, outfall sewer, etc., would be $462,345; for local treatment within the township limits the entire cost would be $398,325.

The township committee on sewerage presented a report in February, 1885, favoring the sewerage system recommended by Mr. Croes, but inclining to the opinion that the sewage should be delivered into the sewers of the city of Newark, which lie between East Orange and the Passaic river, provided a suitable arrangement could be made with the Newark authorities. The committee also recommended that the question of proceeding with the construction be submitted to popular vote at the town meeting in March.

The matter, however, remained in abeyance until the spring of 1886, when Carroll Ph. Bassett, M. Am. Soc. C.E., was engaged to design the details of a plan providing for purification of the sewage within the township limits. The disposal works, in conjunction with a separate system of sewers embracing 26 miles of street mains, were constructed under his direction during that and the following year, and placed in operation in June, 1888. Rudolph Hering, M. Am. Soc. C.E., reviewed the plans as consulting engineer.

In designing the main sewer, it appeared advisable to Mr. Bassett to locate the disposal works as far away as possible from the northeastern district of the township, in which was situated the water-works supplying East Orange and the neighboring town of Bloomfield. These water supplies are derived from shallow wells in the new red sandstone. In accordance with this view, an intercepting sewer was designed, which crossed the northern district from east to west, leading finally into the Second river valley. This sewer would intercept the sewerage of five-sixths of the total area of the township without pumping and deliver it into the northwest section instead of the north-

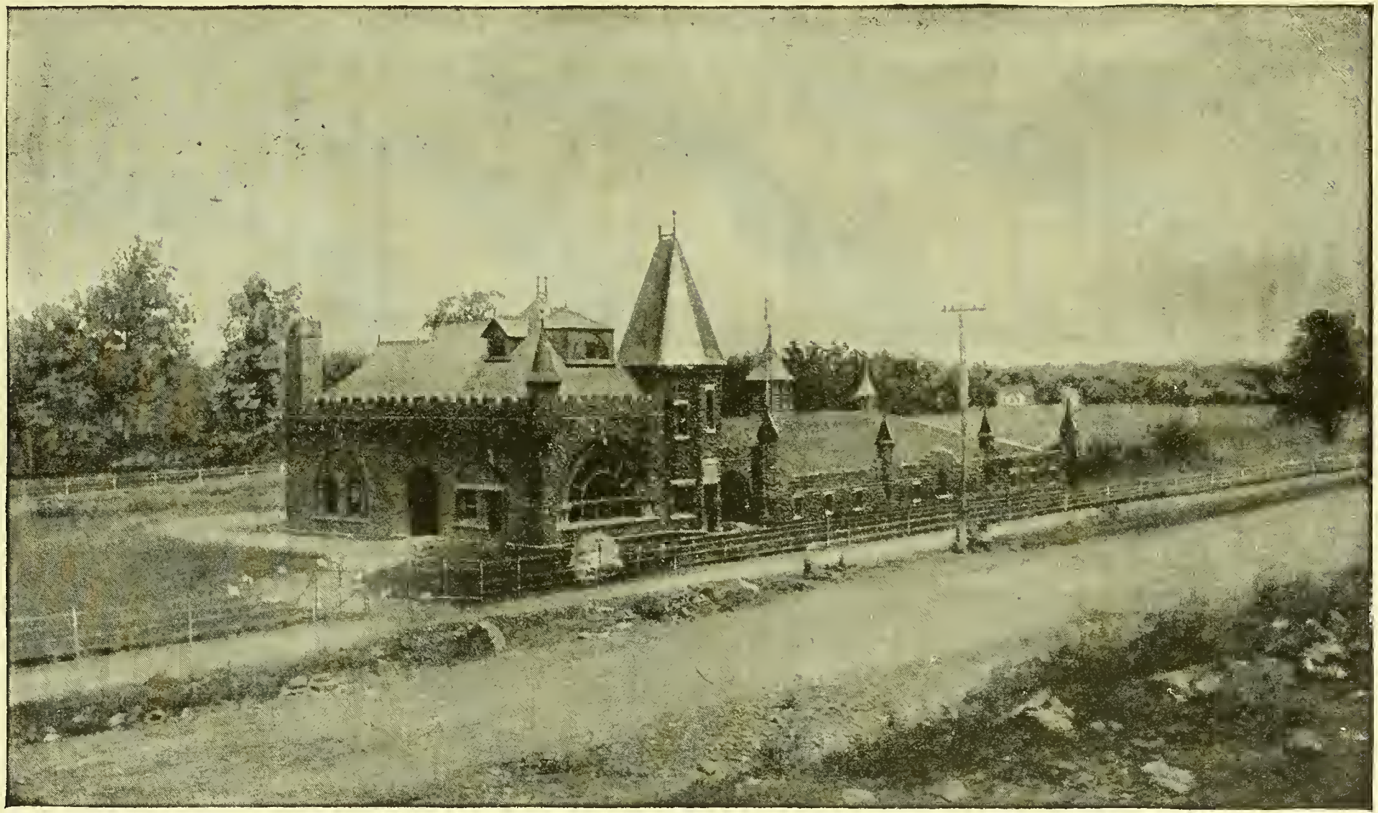


Fig. 46.—General View of Sewage Disposal Works at East Orange, New Jersey.

east. Mr. Bassett considered the arguments in favor of the point of collection which was adopted as : (*a*) A larger percentage of the area of the township could be collected to this point by gravity, than to any other ; (*b*) the sewage would be united at the best point for ultimate gravity extension to tide-water or combination with other towns if it were desired ; (*c*) about the only land in the township available for sewage treatment was there reached ; (*d*) the stream, offering an outlet for the effluent, was larger than any other in the district.

In the chapter on Quantity of Sewage and Variations in the Rate of Flow, at page 132, we have referred to the large amount of ground-water which finds its way by infiltration into the sewers of the East Orange system. Its amount has been as high as about 50 per cent. of the total daily flow, and it has undoubtedly increased somewhat the cost of the purification treatment by necessitating the use of more chemicals than would be required provided the daily flow was confined to sewage proper.

The disposal works designed by Mr. Bassett included a chemical treatment with lime and sulphate of alumina, supplemented by filtration through a coke filter, further supplemented by intermittent filtration through land.

The following is Mr. Bassett's description of the purification works, with slight abbreviations, as presented to the American Society of Civil Engineers :

The land secured for the works was singularly unfavorable for sewage purification. The total area available was about 15 acres ; of this 5 acres were covered by Dodd's mill-pond, and the character of its bottom may be understood, when it is remembered that repeated complaint of its deposits had been made by residents to the Health authorities. The drainage and transformation of the pond was held out to hostile residents as consolation for the location of sewage purification works in their midst. Reference is made to the general plan of the works, Fig. 48. This, together with the views, Figs. 46 and 47, will show the residences immediately adjoining.

The stream indicated on the plan originally fed the pond, but its channel has been deepened and straightened—a rather expensive piece of work, some of the excavation being made in quicksand. It is a tributary of the Passaic, called Second river. Its volume varies from 12 cubic feet per second, in dry weather, to 775 cubic feet per second flood volume. After a flow of about 4 miles it enters the Passaic, near the intakes for the water supply of Newark and Jersey City. Under these conditions it was necessary to secure a very high purity in any sewage effluent which was to be discharged into the stream, and the works must be operated without local nuisance. No reasonable expense was spared to make the works efficient and attractive ; the buildings constituting the works are shown in the photographs, Figs. 46 and 47. A pleasing architectural effect is secured. The masonry is of high class ; deep blue trap-rock, with rock face and worm joints, pointed with red mortar, relieved by red brick trimmings and cut stone capitals at the front about the doors and windows, secure a permanent and attractive appearance to the works.

The sewage enters the works in a 2-feet by 3-feet new form, egg-shaped, brick sewer ; discharges into a conduit of rectangular section, having lateral projections extending nearly to its centre on alternate sides at intervals of three feet along the axis. In this conduit, chemicals from the building join the sewage ; the lateral

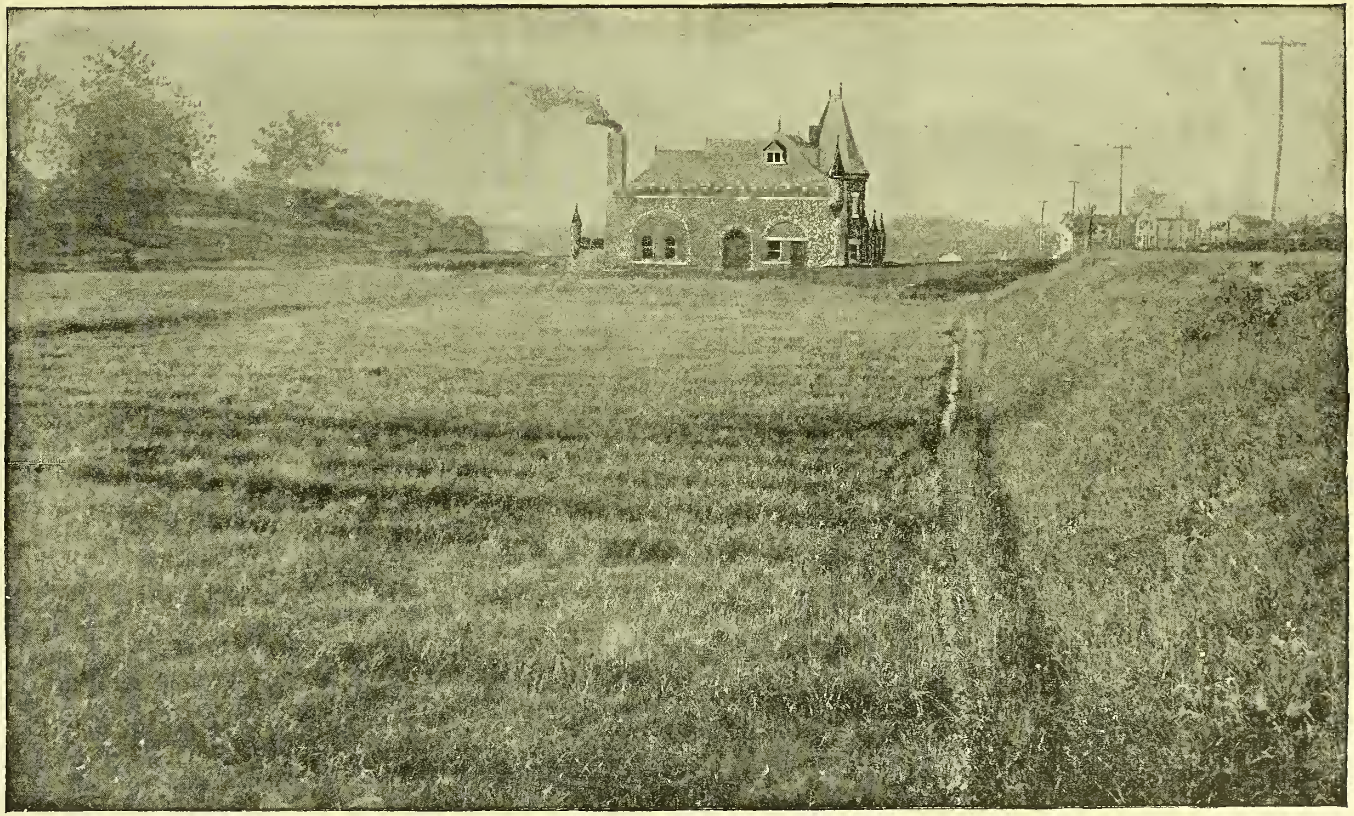


Fig. 47.—View of East Orange Disposal Works showing Portion of Filtration Area.

projections of the carrier give a whirling motion to the sewage, which causes a complete mixture of chemicals with it. The carrier leads the sewage to the precipitation tanks.

The tanks are constructed in duplicate, one set being cleaned or lying idle while the other is in use; Fig. 50 gives a general plan of the building and tanks, with longitudinal and cross sections. A brick wall located 10 feet in front of the inlet to the tanks, checks the velocity of entrance flow. A board floating on edge in vertical guides, intercepts the lighter floating matters, and insures their saturation before passing it. The cross-walls in each tank divide it into three compartments, and the flow passes over these with a depth of about 2 inches, the heavy matters being intercepted and settling. With a continuous flow of low velocity in the tanks, the surface water is being constantly skimmed off into the carrier. Drums float a swivel arm in each compartment, which connects with a low service pipe in the bottom of the tanks that discharges on the surface of the ground at a low level. These arms draw water only from the surface, but the drums falling with the water enable any arm to empty the compartment in which it is located into the low service carrier, leading to the surface of the grounds. The effluent from the precipitation tanks, after entering the carriers (Figs. 48 and 49), is distributed over the surface of the filtration grounds and descends to the under-drains, which are from 3 to 5 feet deep and 20 feet apart over the entire 14.7 acres in the works.

The sewage effluent is applied to the land on the principle of intermittent downward filtration, the flow being applied successively to different areas. Part of the land is laid off in beds, 4 feet wide, separated by shallow furrows, in which the water flows and soaks laterally into the beds. The remainder of the land is divided into flat beds, 100 feet long by 50 to 100 in width, over the whole of which water flows. This latter method is preferable, as more water is disposed of, and in winter, frost is more easily kept out of the ground. Italian rye-grass has given the best results on the land, and is now grown almost exclusively. Farmers from the neighborhood cut the grass and remove it as is necessary, but up to the present time the town authorities have not been able to secure a satisfactory return on its sale.

Within the main building on the first floor are chemical mixing vats, filter presses, sludge-pressing machinery (receivers, air compressors and pump), boiler, and a small office for records and tests (Fig. 50). On the second floor chemicals and materials are stored. The chemical mixers are cylindrical cast-iron vats, 4 feet in diameter, with inverted cone-shaped bottom overlayed with a perforated plate. The desired amount of chemicals is placed on the plate, water is let into the tank, and air blown up through the bottom, causing violent agitation of the liquid and resulting in the rapid solution of the chemicals. With a known flow of sewage at a given time, it is determined how wide to open a slide-valve in the bottom of the tank after solution of the chemicals is secured, in order to add the desired number of grains per gallon of sewage.

The sewage is mainly of a domestic character and somewhat constant in its alkalinity. Not more than 3 grains of lime and 2 grains of sulphate of alumina are now added to each gallon of sewage by the authorities, although when the works were placed in operation, the author recommended the use of 8 grains of lime and 10 grains of sulphate of alumina per gallon of the sewage. The present result is a less efficient precipitation. A combination of chemical precipitation and land filtration in the works makes it possible to increase the work performed by the land by reducing the efficiency of chemical treatment, and *vice versa*. The labor of purification now placed upon the grounds is greater than its equitable share as originally intended. Much better results could be secured by calling out the full efficiency of the chemical treatment. To relieve the filtration grounds, which have rather a retentive soil, several artificial filter-beds of coke and gravel were constructed under my direction, and have been of material service. (See Fig. 48.)

Returning now to the precipitated matter of sludge in the tanks: after the supernatant water is drawn off through the swivel-arm into the low-service carrier, a valve gate is opened and the sludge drawn into the deeper sludge-well within the build-

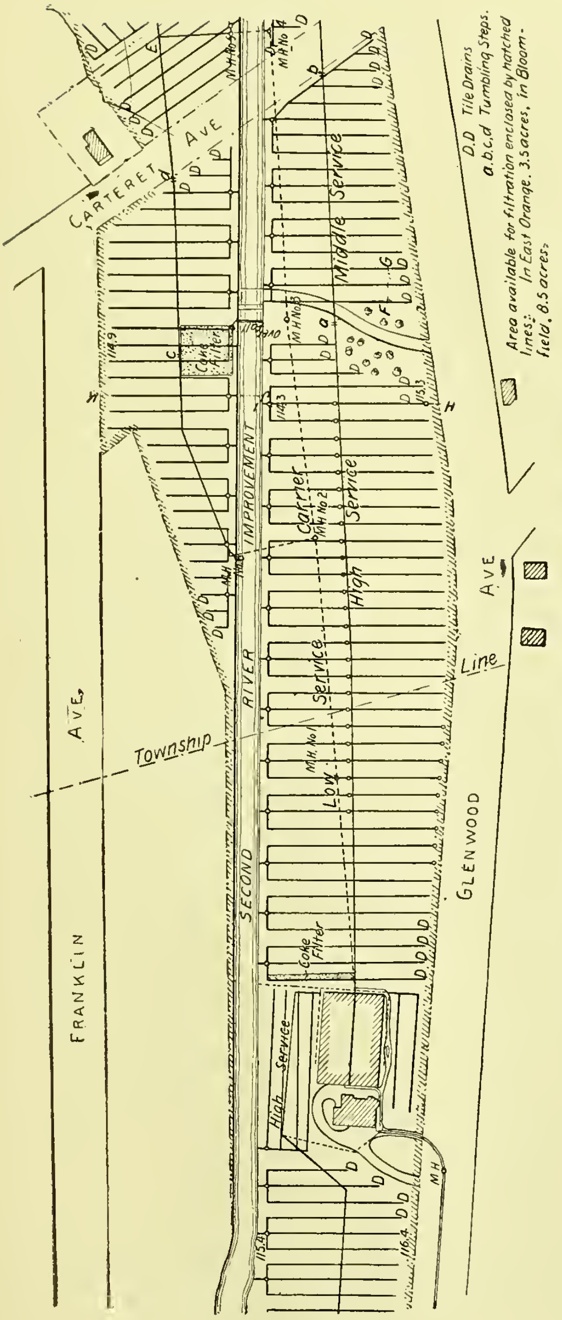


FIG. 48.—GENERAL PLAN OF EAST ORANGE SEWAGE DISPOSAL WORKS.

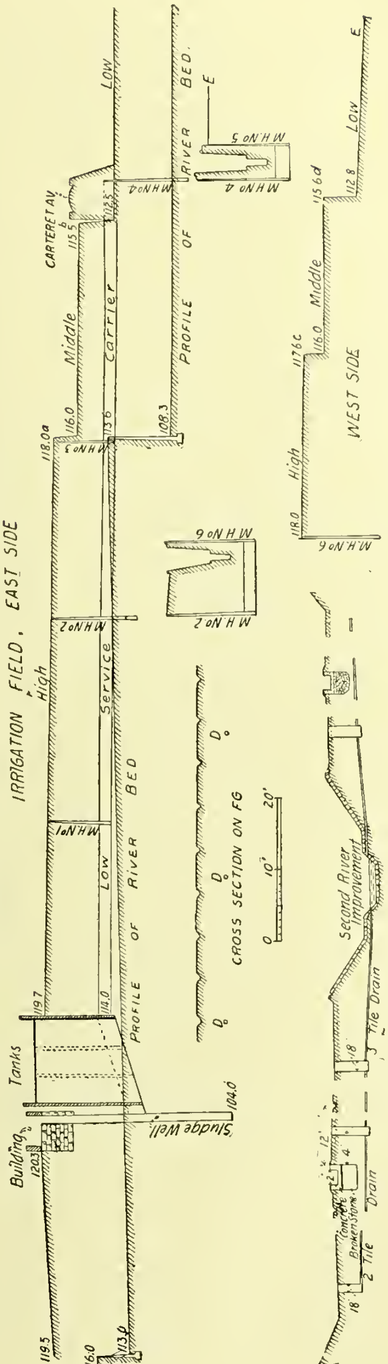


FIG. 49.—SECTIONS THROUGH DIFFERENT PORTIONS OF THE EAST ORANGE DISPOSAL AREA.

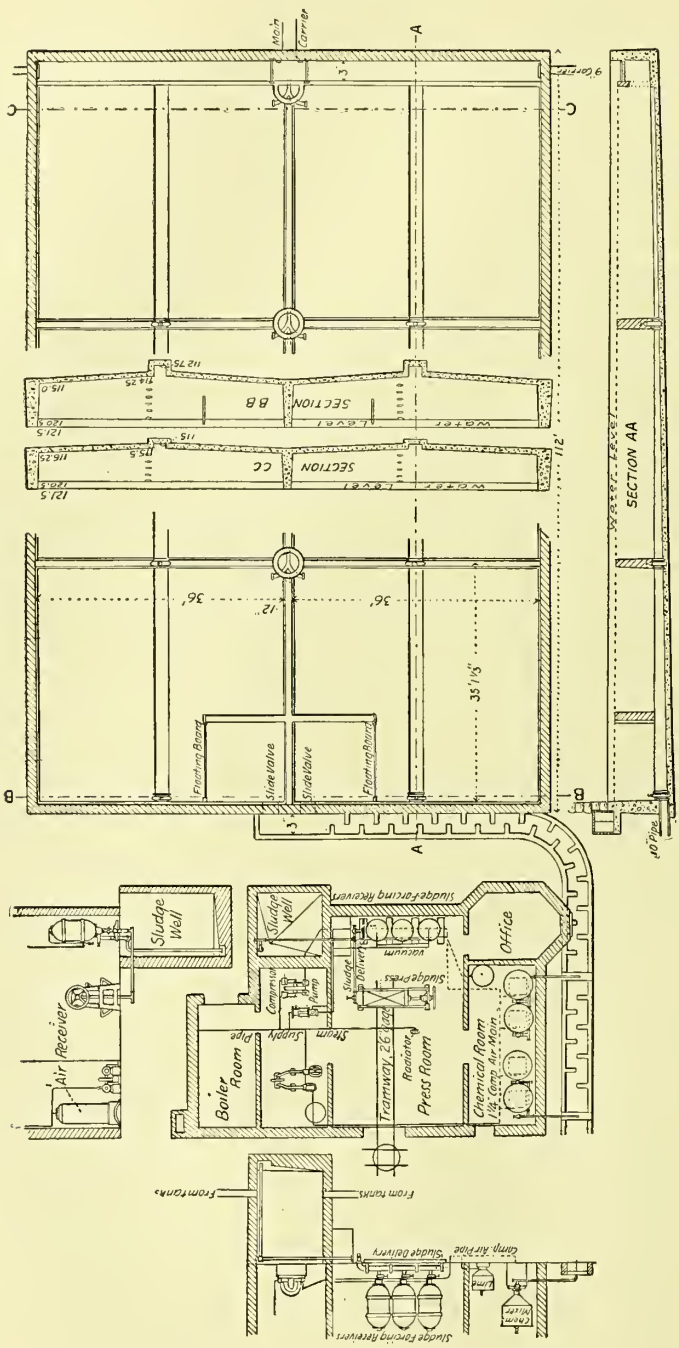


FIG. 50.—PLANS AND SECTIONS OF EAST ORANGE CHEMICAL PRECIPITATION WORKS.

ing. By forming a vacuum in a cast-iron receiver, which is connected by an iron pipe with the sludge-well, the sludge is drawn up into the receiver, milk of lime being drawn in at the same time, by a small pipe from the mixing tank in the chemical room. This lime prepares the sludge for pressing, cutting the slime so

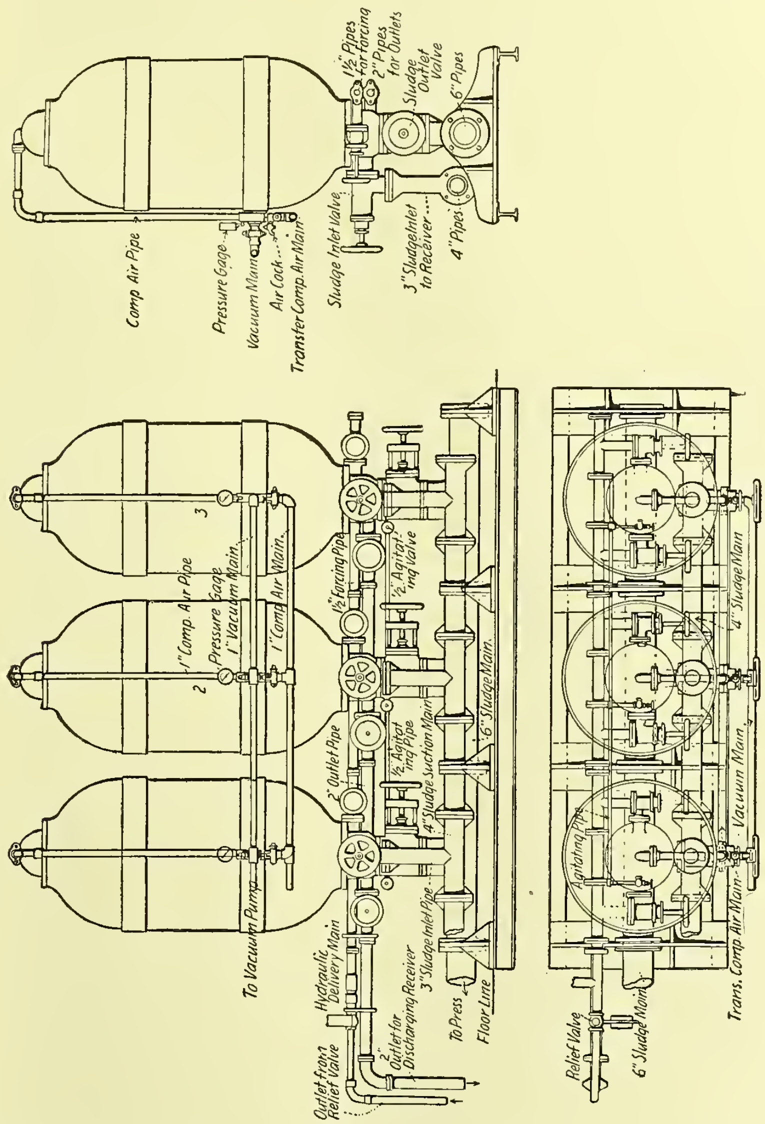


FIG. 51.—EAST ORANGE SLUDGE AND FORCING RECEIVERS.

that the water separates more readily from the solids. A pressure of 100 pounds per square inch is secured in one of the other receivers, and, being connected with the receiver containing the sludge by an air transfer main and the proper valves opened, the sludge is forced into a Johnson filter-press and pressed into moist, hard, portable cakes.

An analysis of fresh sludge directly from the press, made September 11th, 1889, by Mr. Charles T. Pomeroy, of Newark, N. J., gave results as follows:

Nitrogen from organic matter	.326	per cent.
Total phosphoric acid	.459	"
Moisture	50.625	"

Using the 1889 trade values adopted by the New Jersey experiment station we have an estimated worth of $1.51 per ton, 2,000 pounds. This sludge quite rapidly lost its moisture on exposure to the air, until it contained 6.37 per cent. moisture. If dried at 100 degrees C. it would have an estimated value of $3.06 per ton, 2,000 pounds.

The machinery used in manipulating the sludge was constructed by S. H. Johnson & Co., Stratford, England, who have erected numerous plants in England. Their machinery is the subject of several patents, and no similar devices are manufactured in this country. Not all of the machinery furnished has been satisfactory. The combination vacuum and compression pump and the high-pressure water-pump gave considerable trouble, and have been replaced by a Clayton compressor . . . . and a Worthington duplex pump . . . . .

The method of maintaining and securing the pressure in the hydro-pneumatic receivers to press the sludge is worthy of brief comment. There are three receivers in the system (see Fig. 51); let them be represented by *A*, *B* and *C*. Air passes out at the top, sludge at the bottom, water enters at the side near the bottom and exits at the bottom. All the receivers are empty, except of air. Water is pumped into *A* and *B* and the air transfer mains opened to transfer their air to *C*, raising the pressure to 45 pounds per square inch. The valve on the air main from *C* is closed. The water in *A* and *B* is drained back into a shallow tank in the floor of the building with which the pump suction is connected—air taking its place. Water is again forced into *A* and *B*, operating proper valves, and the pressure in *C* is raised to 75 pounds per square inch. A repetition of this process brings the pressure in *C* to 105 pounds per square inch. *A* and *B* are emptied as before and a vacuum in *A* created, the sludge suction pipe is opened, and *A* is filled with sludge. Water is now pumped into *B*, forcing its air into *C* and thence into *A*, to force the sludge into the press. When *B* is filled with water, *C* may be filled with air, and *A* with sludge and air. When a receiver is filled with water, a float valve at the top closes the outlet to the air transfer main, and weighted valves on the force main lift and relieve the pressure on the pump.

The value of the process now first appears. *B* is emptied of water and filled with sludge, while at the same time water is being forced into *C*, and by connection with *A* forcing the remainder of its sludge into the press. Compressed air is thus never allowed to escape into the atmosphere. When *C* is filled with water, it is ready to be filled with sludge, while at the same time water is forced into *A* and the sludge of *B* forced in the press.

The filter press shown in Fig. 52, consists of thirty-six cast-iron cells, supported on a simple frame, with a central feed-passage into which the sludge is forced from the receivers. The cells are separated by canvas bags, and in the intercellular spaces the sludge remains, while the water is drained out through the canvas bags into a trough on the rear of the press, and returns to the tanks. On the end of the press is a capstan-screw connected with a thrust-block which presses the thirty-six cells of the press into close contact. It is the air pressure which separates the water from the sludge.

There is nothing offensive about these cakes when pressed dry; and if protected from water after being taken from the press, they may be kept in bulk for weeks without nuisance. In the presence of heat and moisture they become more or less objectionable. The manurial value of the sludge cakes is slight. The small amount of precipitants used fails to retain the bulk of fertilizing matters in the sewage. At present between 9,000 and 10,000 people are contributing to the sewage, and about 13 tons of sludge are taken out each week. Some of the sludge cake has been sold at fifty cents per load; but more has been given away among neighboring farmers, while a large amount has been carted away by the authorities for burial when no other removal offered.

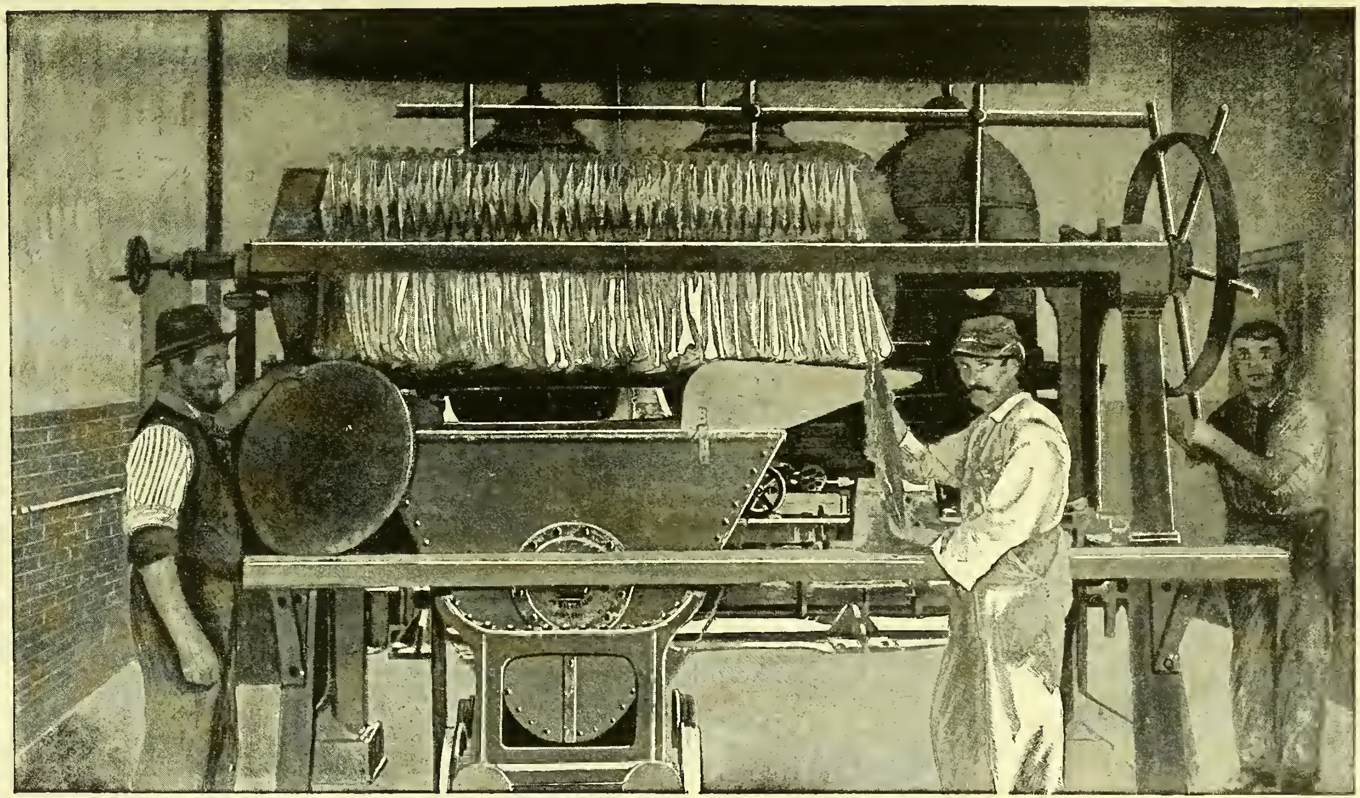


Fig. 52.—Johnson Filter Press in Operation at East Orange.

A committee of the "Town Improvement Society of East Orange" . . . determined during the summer and fall of 1890 to investigate the operation of the works and their results. They secured and submitted to Professor A. R. Leeds two samples of effluent water for examination and report. The results generally are better than results secured for the author's use from time to time. . . .

The summary of Professor Leeds' analyses, as quoted by Mr. Bassett from the committee's report, and such of Professor Leeds' comments as are necessary by way of explanation, are as follows:

ANALYSES OF EAST ORANGE SEWAGE EFFLUENTS, COMPARED WITH UNTREATED SEWAGE.

(Parts per 100,000.)

	Free ammonia.	Albuminoid ammonia.	Oxygen required to oxidize organic matter.	Nitrites.	Nitrates.	Chlorine.	Total hardness.	Permanent hardness.	Temporary hardness.	Total solids.	Mineral matter.	Organic and volatile matter.
Raw sewage	1.0 to 1.5	.30 to .70	....	....	....	5 to 10	....	....	8 to 12	40 to 108	18 to 91	7 to 22
(1) Effluent from coke filter*	0.087	0.027	0.44	0.0	0.26	6.12	15.60	3.00	12.60	29.60	23.50	6.10
(2) Final effluent	0.02	0.003	0.40	0.0	0.38	4.00	20.00	12.50	8.50	25.50	22.00	3.50

* Sewage passes through small coke filters at its exit from tanks.

Sample No. 1. Taken from the flow as it emerges from the coke filter as the sewage leaves the tank.

When received—Sept. 8, 1890. Color—Turbid with white flocks. Taste—Not tried. Smell—Unpleasant, musty.

The results above stated indicate the presence of a large amount of unoxidized sewage. I should also suspect that this sample represents sewer water which has received the addition of some lime, taken at a point before the benefit of this treatment has been obtained. The effect of the addition of lime is to increase the temporary hardness (in the above analysis it is 12.6 parts per 100,000), after this lime has operated, by combining with the large amounts of carbonic acid contained in sewage, and the carbonate of lime resulting from this combination has precipitated, carrying with it much of the organic matter.

Sample No. 2. From the final effluent into the brook.

When received—September 8, 1890. Color—White, clear. Taste—Not tasted. Smell—Not pleasant, slightly musty.

It will be seen that the temporary hardness diminishes, and the benefit of the treatment becomes apparent. The second sample is strikingly different from No. 1. It shows an almost entire disappearance of the nitrogenous organic matter, the free ammonia being only $\frac{1}{40}$th and the albuminoid ammonia $\frac{1}{9}$th of the amounts present in sample No. 1. This disappearance is evidently due to oxidation, since the nitrates (which arise from the absorption of oxygen under the influence of nitrifying bacteria in the ground) are strikingly increased. I should suspect this sample to represent aërated sewage water which has passed through the ground. In its passage its sewage impurities have been effectually removed, and the substances remaining are such as are found in country streams in their natural unpolluted condition.

I should certainly feel far less sense of danger in drinking the sewage effluent, as represented by the samples sent from the East Orange Sewage Disposal Works, than in drinking the water of the Passaic river, as pumped at Belleville and supplied to the inhabitants of Jersey City. Your effluent (September 8th, 1890) contained 0.0017 grains of albuminoid ammonia per gallon; the Passaic river, at

Belleville, on the date of my last analysis (June 14th, 1890) contained 0.01 grain per gallon. In other words, taking the albuminoid ammonia as the measure of sewage contamination, the Jersey City water contains six times more sewage than the effluent waters from your works.

As chemist for the Jersey City Board of Public Works, from 1881 to 1886, I found very many samples of the Passaic water even worse than the above.

I regard the performance of your works and the character of the effluent as satisfactory from both the practical and sanitary standpoints.

Mr. Bassett resumes his description of the works as follows:

The total cost of the works to January 1, 1891 (including about 4 miles of extensions constructed since my connection with the work), is given as follows:

Chargeable against sewerage system (29 miles)......	$322,020.64
Disposal works plant..............................	75,098.60
Disposal works land (including 4 acres not used)....	20,749.20
Total..	$417,868.44

The cost of operating the works has been—

July, 1888, to March, 1889..................	$562.00	per month.
March, 1889, to March, 1890...............	746.00	"
March, 1890, to January, 1891..............	881.00	"

The average daily flow of sewage reaching the disposal works is approximately 1,300,000 gallons, or an average of about 90,000 gallons per acre. The need of the coke filters is therefore apparent. This daily flow may be approximately divided as follows:

Ground-water from 25 miles, constructed under my direction..............................	550,000	gallons.
Ground-water from 4 miles, constructed since June, 1888..................................	100,000	"
Flush-tank flow..............................	30,000	"
House sewage flow...........................	620,000	"

According to a statement made by Mr. Bassett in August, 1891, at that time the several items which entered into the expense of operation, were approximately as follows:

Engineer and laborers at building, coal and water, oil and waste	$300	per month.
Chemicals, including lime	200	"
Manager and two helpers on grounds................	155	"
Removal of sludge.	70	"
Total..	$725	"

About 15,000 people are stated as contributing sewage at the time of the foregoing statement. The annual per capita cost of maintenance, therefore, exclusive of interest charges, was about 60 cents.

Mr. Bassett states that this per capita cost will probably reduce as experience and volume of sewage increase.

Later information regarding the cost of treatment and other feat-

ures of the works was obtained by a personal visit in November, 1892, as follows :

Mr. J. J. O'Neill, Township Engineer of East Orange stated that the cost of operating the works for the nine months from January 1 to October 1, 1892, had been as follows:

Labor	$3,935
Chemicals, coal, oil, canvas, repairs, sundries	2,146
Total	$6,081

This is at the rate of about $675 per month, or $8,100 per year, or about 56 cents per inhabitant per year, on a basis of a population of 14,500. The decreased cost of operating the works in 1892 is said to have been due to greater efficiency of labor. The force at the disposal works in November, 1892, included a foreman, engineer, and five laborers. The tanks are cleaned three times a week, and their sides whitewashed or treated with some other disinfectant. The sludge cakes are generally drawn to the poor farm and there buried or disposed of otherwise.*

Lime is bought of a local dealer at 95 cents per barrel, delivered at the works. Sulphate of alumina costs about 1¼ cents per pound at the works, and is bought by the carload from the New York branch of Harrison Bros. & Co., Philadelphia.

In November, 1892, there were in use about 33 miles of sewers and 1,685 house connections. Most or all of the flush tanks were not in use in 1892, and the daily flow of sewage for that year is given at 1,200,000 gallons, which is said to be less than it was previously, owing to a decrease of infiltration of ground-water to the sewers.†

* July 15, 1893, it was stated at the disposal works that the sludge was being drawn away by farmers, without compensation on either side; also, that to that date two crops of grass had been cut from the disposal area.

† The sources of information in regard to the Sewage Disposal Works at East Orange are :

(1) Mr. Bassett's paper, Inland Sewage Disposal, with Special Reference to the East Orange, N. J., Works. Tran. Am. Soc. C. E., vol. xxv. (1891), pp. 125–160.

(2) The East Orange, N. J., Sewerage System. Eng. News, vol. xxi. (Jan. 5 and 19, 1889), pp. 42–43.

(3) Sewerage of East Orange, New Jersey. Eng. and Bldg. Recd., vol. viii., (1883) p. 45; also vol. xi. (1885), p. 313 ; also vol. xix. (1889), pp. 87–88 and 107–109.

(4) The East Orange Sewage Disposal Works as Compared with Other Methods. Abstract of paper read before N. J. San. Assoc., Trenton, Nov. 22, 1889. By Carroll Ph. Bassett, 13th An. Rept. N. J. St. Bd. Health (1889), pp. 73–82; also in revised form, Eng. News, vol. xxiii. (Feb. 15, 1890), pp. 160–162.

(5) The reports of Mr. Croes and the Committee on Sewerage, etc., of the Town Improvement Society.

(6) Sewage Purification in America. East Orange, N. J. Eng. News, vol. xxviii. (Dec. 1, 1892), pp. 520–521.

CHAPTER XXV.

CHEMICAL PRECIPITATION AND MECHANICAL SEPARATION AT LONG BRANCH, NEW JERSEY.

In the fall of 1884 the local health authorities of Long Branch, New Jersey, consulted Carroll Ph. Bassett, M. Am. Soc. C.E., in regard to the introduction of sewerage into that town.

On investigation it was found that, while urgent need existed for an efficient removal of sewage, the limit of the city's bonded indebtedness had been almost reached. An increase in the limit could only be secured by a popular vote, and would probably have been defeated.* It was finally decided to allow a company to build works. The necessary legislation was obtained, and a private company, incorporated under the State law, introduced a system of sewerage. A number of the public-spirited citizens of Long Branch were interested in the control of the sewerage company, and it was considered that a matter so intimately related to the health of the town could be safely intrusted to their hands. Surveys were made and plans perfected in the winter of 1885–6, and in the following spring the main portion of the sewerage system was constructed.

In the agreement between the town and the company it was stipulated that no objectionable matters should be poured into the adjacent waters; hence the introduction of some process of purification was imperatively necessary. To meet the requirements, a system of partial chemical precipitation, supplemented by filtration through coke, was devised.

The system has been described by the engineer as follows:

> The topography of the town is simple. A ridge, twenty feet above mean tide, rolls up from the beach and falls easily back to a parallel valley, 500 to 600 yards from the beach, which averages nine to ten feet above mean tide throughout the length of the town. The west slope of the valley rises gradually for a fraction of a mile, where it again dips to form a secondary valley. This second ridge is intersected by several streams and depressions. It would have been a simple matter to construct sewers adapted to the needs of the built-up portion of the town, but to design a comprehensive system capable of extension and development to meet the needs of the entire adjacent territory, and conditioned on the location of the works

* In regard to the sanitary condition of Long Branch previous to the construction of the sewerage works, see (1) A Report on an Inspection of Certain Health Resorts. By E. W. Bowditch, San. Eng., in Rept. Nat. Bd. Health for yr. end. June 30, 1882, pp. 153–187; (2) 7th An. Rept. N. J. St. Bd. Health (1883).

for the treatment of the sewage, was a complex problem of considerable magnitude, and required an expense in construction only justified by the demands of the future, and in the making of which the company are stated to have demonstrated their good faith and determination to meet the needs of the entire community.

The system constructed is the "separate" system. The sewage is collected in vitrified pipes (eight-inch being the minimum) into the main, which flows in the principal valley (twenty-four-inch being the maximum); passes through the build-

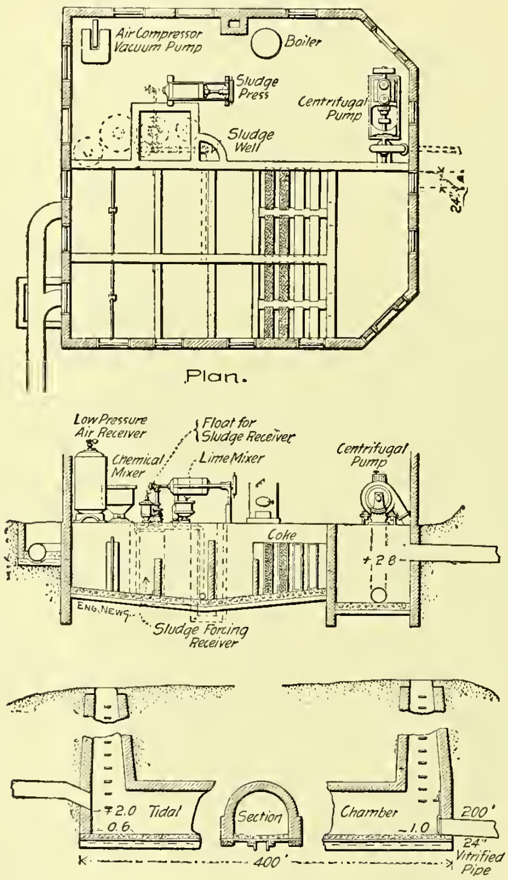


Fig. 53.—Plan and Sections of Purification Works at Long Branch, New Jersey, and Sections through Tidal Chamber.

ing, where it undergoes the treatment; thence to the tidal chamber, in which it is controlled by automatic valves and discharged on the outgoing tide into the ocean through a wrought-iron pipe supported on piles and extending 200 feet from shore.

Man-holes are placed along the lines at intervals not greater than 300 feet, and at all deviations of alignment or grade, securing control and location of troubles in the pipes. The covers are perforated to secure ventilation, and buckets are to be hung just beneath the covers to catch dirt and sand falling through the holes.

As the sewers are designed to accommodate the maximum flow of the crowded season, the main does not receive cleansing flow during a large portion of the year.

Arrangements are made for liberal flushing along the lines, and in some locations the brook can be turned into the sewers.

In the section of the town to which the sewage would gravitate, little available land for treatment-works could be obtained; and the main sewer was necessarily located at so small a height above mean tide that considerations of economy de-

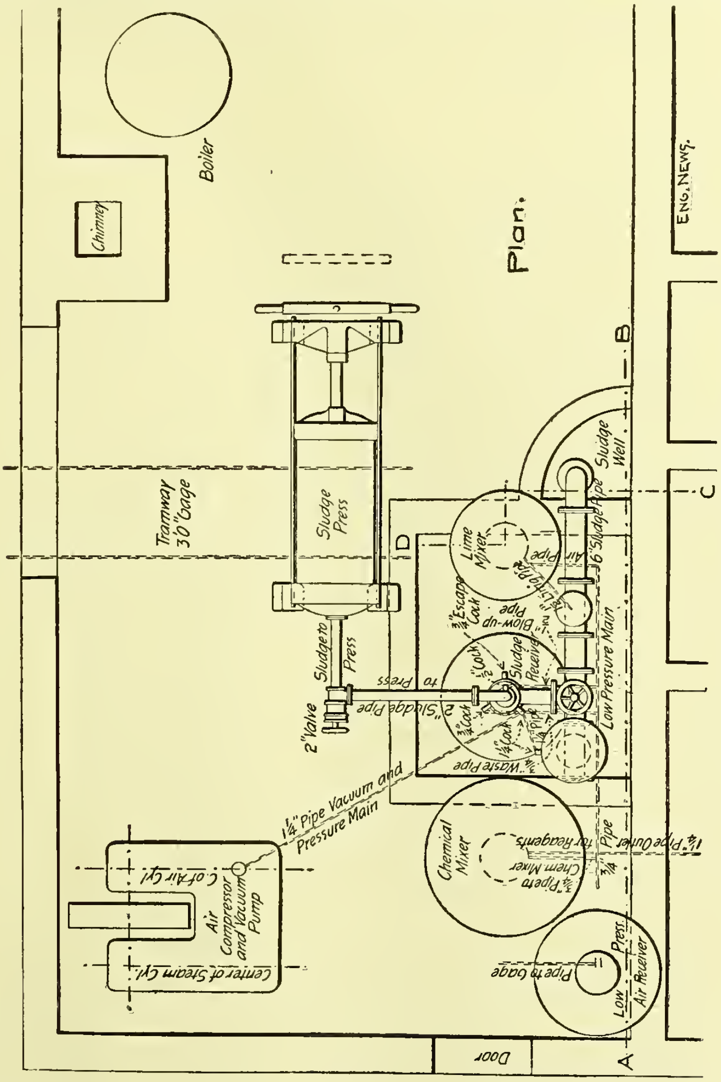


FIG. 54.—PLAN OF SLUDGE COMPRESSORS.

pendent on a gravity outlet demanded that the shortest line to the ocean be provided. This prevented any lengthy detour of the main sewer to treatment-works, and virtually determined their location. A small plot of ground, 100 × 100 feet, on Long Branch avenue, near Second avenue, was finally procured and the works erected there. The building is surrounded, close on every side, by dwellings and shops. Chemicals (lime, alum, etc.) are mingled with the sewage at its entrance to

the works. Together they flow into the receiving tanks, which are constructed in duplicate of concrete, and receive the sewage alternately, the one being cleaned while the other is in use. The course of the sewage in the tanks, under planks floating on edge, over walls, through submerged arches, as shown in the accompanying sketch (Fig. 53), is such that in the thirty-feet flow a large part of the matters in suspension settles with the chemicals into the bottom of the tank; the sewage then enters the series of portable coke filters. Provision is made for four deep, narrow wire cages, sliding in guides and holding different sizes of coke.

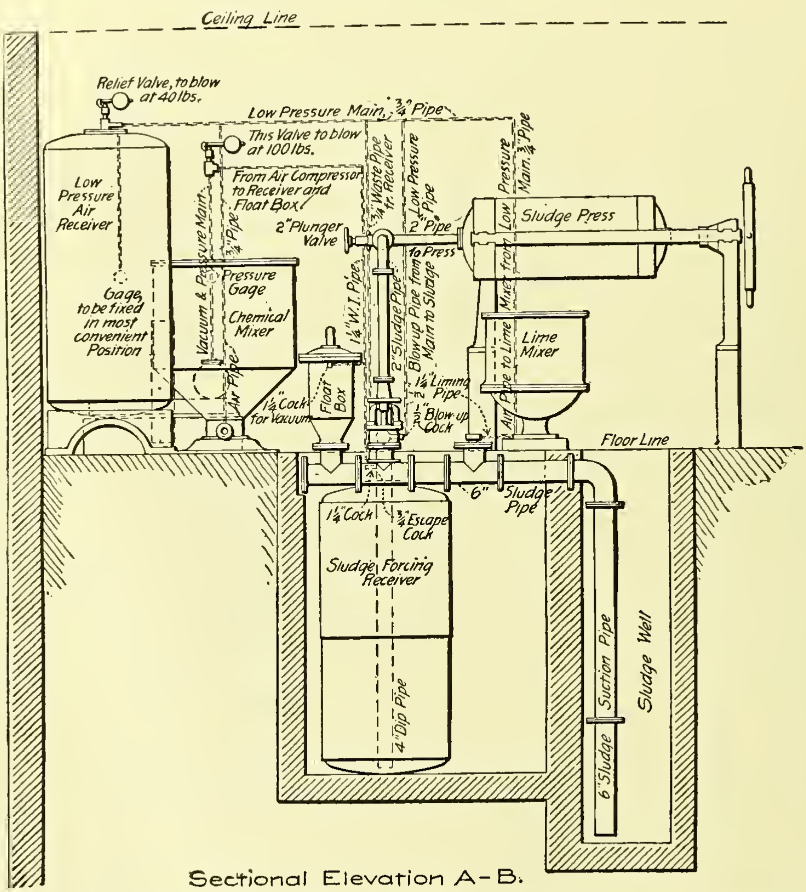


FIG. 55.—DETAILS OF SLUDGE COMPRESSORS, LONG BRANCH, NEW JERSEY.

When the filters are clean a very fair purity is secured, and it is believed that the process is capable of considerable development. The coke when taken from the frames is used as fuel; it could with care be used again as a filter, effecting economy. The flow in the tanks is continuous. Considerable loss of head occurs in the flow through the filters, and when they are in operation the sewage has to be pumped up to the level of the gravity sewer. This is accomplished by a six-inch centrifugal pump, built by the Weber Machine Company, of Lawrence, Massachusetts. When the filters are out the sewage passes through the works by gravity. After sufficient deposit is secured in one of the tanks the flow is diverted to the other, and the water is drawn down in the first tank nearly to the level of the

sludge (or deposit); the remaining contents of the tank are then drawn into a wrought-iron sludge-receiver by creating in it a vacuum with a vacuum engine. From this receiver the sludge is forced by compressed air into Johnson's filter-press, where the liquids are pressed from the sludge, leaving portable cakes to be used as guano. A by-pass is arranged on the main sewer near the building, so that sewage, in case of accident or emergency and during the winter season, can be made to flow by gravity directly to the tidal chamber, avoiding the works.*

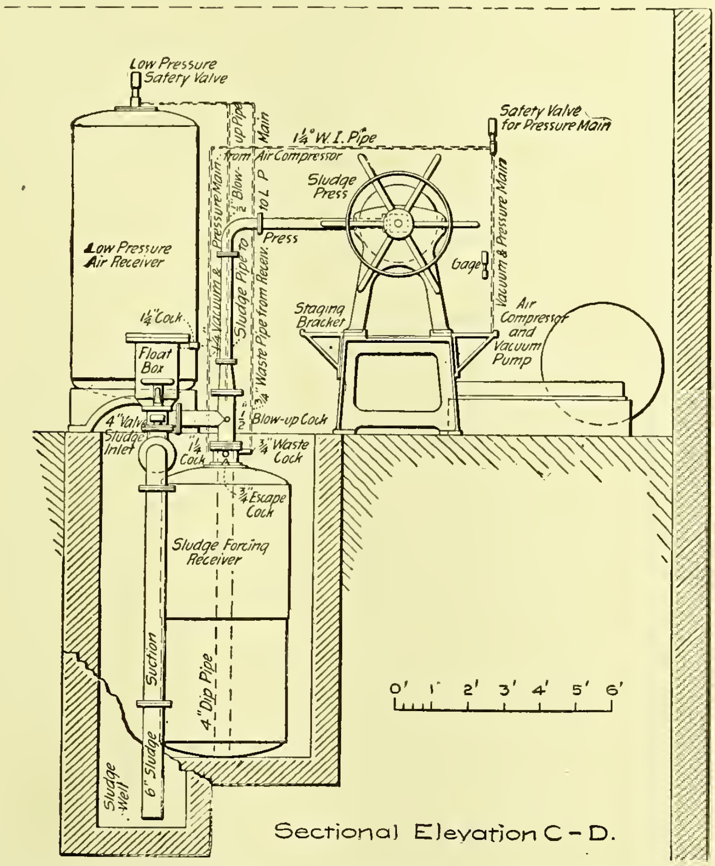


FIG. 56.—DETAILS OF SLUDGE COMPRESSORS, LONG BRANCH, NEW JERSEY.

The population of Long Branch in winter does not exceed 7,000; in summer it is estimated at 80,000.

The sewers receive some roof-water at the head of the lines.

On a visit to the plant Dec. 1, 1892, the following additional information was secured through the courtesy of the officials of the company:

There were in use on the above date about ten miles of sewers and

* Description of Long Branch Sewerage System. By Carroll Ph. Bassett, 11th An. Rept. N. J. State Bd. Health (1887), pp. 88–91.

400 house connections. The tidal chamber provided to permit of discharging the sewage at high tides is not used, difficult construction and economy having resulted in a chamber too small for practical use. During heavy rains in the winter season no attempt at purification is made, the sewage passing around the station directly to the ocean.

About 75 pounds of alum a day, costing $1\frac{1}{2}$ cents per pound in New York, has been used since the plant was put in operation. Lime is used for treating the sludge, only a small quantity of the latter, it appears, being secured. The sludge is given to one of the directors of the company, who uses it on his farm. The sewage passes through two coke filters, and the coke is renewed only once a year at a cost of about $2. No records of the amount of sewage treated, or of the daily flow, are kept.*

* See Eng. News, vol. xxviii. (Dec. 22, 1892), pp. 580–582.

CHAPTER XXVI.

THE MYSTIC VALLEY CHEMICAL PRECIPITATION WORKS.

THE water supply of the Charlestown district of the city of Boston, and of the towns of Chelsea, Everett, and Somerville, is derived from the upper Mystic lake, which is about $6\frac{1}{2}$ miles from Charlestown, in the towns of Medford, Arlington, and Winchester. Its area is about 200 acres; drainage area, $27\frac{3}{4}$ square miles; and mean surface elevation, about 7 feet above tide-water. The storage capacity is about 380,000,000 gallons.

In Winchester and Woburn, near the head of the upper Mystic lake, are about a dozen tanneries, the drainage from which formerly passed directly into the upper lake. A considerable amount of house-drainage also passed into the Abbajona river (the influent stream to the Mystic lake) or into its tributaries. The effect of this drainage was to seriously pollute the Mystic lake. After the acquirement of the Mystic supply by the city of Boston, it was concluded to construct a sewer to intercept this objectionable drainage and convey it to the lower Mystic lake, which is subject to tidal action. An Act was passed by the Massachusetts Legislature in 1875, authorizing the construction of such a sewer, but by reason of defects in it nothing was done until after the passage of an amendment in 1877. Immediately thereafter an order of the City Council was approved, authorizing the construction of the sewer in conformity with the provisions of the original Act and the amendment. The entire work, including the main sewer and its branches, was completed in the summer of 1878.

The main sewer, 11,857 feet in length, extends from the head of the lower Mystic lake to a point in Woburn, near Moseley's tannery. It is 28 inches high and 26 inches wide, except at the outlet and along a railroad embankment near the upper end, where cast-iron pipes 24 inches in diameter were used. Branch sewers, to the amount of 11,664 feet, were constructed to various points, where the tannery and other objectionable drainage was to be intercepted; 6,150 feet of these are 15 inches in diameter, 2,000 feet 10 inches in diameter, with the balance 6 inches in diameter.

The Mystic valley sewer presents some interesting phases of legislation in reference to sewerage and sewage disposal. During the year 1880 complaints were made by the towns of Medford and Arlington

that the accumulation of sewage in the lower Mystic lake was the cause of a serious effluvium nuisance, and the Legislature was appealed to for its abatement.

The result of this action was the enactment of a law ordering the discontinuance of the sewer, unless the sewage be so treated as to render it free from polluting substances. The peculiar nature of the tannery sewage, which consists mainly of the refuse of tanneries, such as spent tan bark and scrapings of hides, appeared to render it a very difficult problem to comply with the requirements of the Act, and in order to learn authoritatively what could be accomplished by chemical treatment of this particular sewage, the Boston Water Board requested Professor Wm. Ripley Nichols to examine a sample of the sewage and report upon the same. The following is from his report, submitted in February, 1881:

The sewage was received by me late in the afternoon of January 28th, having been taken from the sewer that afternoon. It was alkaline, reddish brown in color, and containing a quantity of suspended matter, the coarser part of which settled somewhat readily. The odor, when the sample was fresh, was not very considerable, but was sufficiently marked to betray its origin. On standing in the laboratory, the organic matter, as might be expected, began to decompose and became very much more offensive.

The specific gravity was about 1,007, water being 1,000. Analysis showed that every 100,000 parts contained about 330 parts by weight of suspended matter and 1,170 parts of matter in solution; or, expressed in grains to the United States gallon, one gallon contained:

	Grains.
In suspension	192
In solution	683
(Of which 432 grains were common salt.)	
Altogether	875

I have made a number of calculations and experiments with reference to the chemical treatment of the sewage, but I do not know that this was a fair sample of the entire daily discharge, which I have assumed to be 200,000 gallons, or say in round numbers, 1,700,000 pounds.

Subsidence.—When the sewage stands quietly, the greater portion of the suspended matter settles, but the liquid still remains turbid and highly colored and liable to decompose. If the sewage were allowed simply to settle in tanks and the somewhat clarified liquid then run off directly or through coarse filters, the sediment could be removed as a thin mud.

The weight of *dry* sediment for the day's discharge would be some 5,600 pounds, and when wet (that is, in the form of sludge, which would run slowly or could be pumped) it would occupy about 12,000 gallons.

I am, of course, aware that at the present time settling tanks are in use in the tanneries, and that thus a large amount of solid matter is prevented from entering the sewer.

Treatment with lime.—The sewage, as I received it, was alkaline, no doubt from the excess of lime used in the tanneries, and the addition of a small quantity of lime had no effect on the clarification of the liquid. Even when added to the amount of two per cent. by weight (which would be 35,000 pounds of quicklime for the day's run), it failed to produce any very considerable effect. With the enormous proportion of $\frac{1}{6}$ by weight (290,000 pounds of quicklime for the day's run), quite an efficient clarification was accomplished by the subsiding of the lime; but any such proportion as this would be out of the question from a practical point of view.

Even in this case, however, the liquid still contained organic matter in too large a quantity to be discharged into a salt-water basin without being liable to cause offence.

Treatment with alum.—On the addition of alum (or sulphate of alumina) in sufficient amount, there separates readily from the sewage a rather bulky precipitate containing almost all the coloring matter, even in solution, and leaving the liquid clear and nearly colorless. As the experiment is performed in the laboratory, better results are obtained by this method than by any other; but to produce the best effect it is necessary to add as much alum as from $\frac{1}{4}$ to $\frac{1}{3}$ of one per cent. of the sewage. To treat in this way the daily discharge of sewage would require from 4,000 to 6,000 pounds of alum, or an equivalent amount of sulphate of alumina. The expense of the chemical puts this out of the question, and, if it did not, we should have to face the fact that the sediment formed would, after twenty-four hours' standing, occupy when wet the space of 60,000 gallons; moreover, with the best clarification that I have been able to effect, the clear liquid still contained, in solution, a large amount of organic matter ready to decompose.

Treatment with clay.—I was not able to obtain satisfactory results by using clay, although when a considerable quantity was added to the sewage and thoroughly mixed with it, a certain amount of organic matter was dragged down as the clay settled. Such treatment, if applied practically, would increase very much the weight of sludge to be handled; but I have made no calculations of the amount of clay required.

Treatment with sulphuric acid.—When acid is added to the sewage in just sufficient quantity to neutralize its alkaline character, the liquid clears itself quite well, most of the coloring matter subsiding as a flocculent sediment. The liquid still contains a large quantity of organic matter; but if, after treatment with acid, it were filtered and then allowed to flow over fragments of limestone or marble chips, to neutralize any excess of acid, it would no doubt give less offence than at present. The amount of acid required for this particular sample would be equivalent to about 2,000 pounds of oil of vitriol for the day's discharge, and the wet sludge would occupy about 20,000 gallons.

You will bear in mind that my experiments have been performed, and my conclusions are based, on a single sample of sewage; I have no means of knowing how fairly it represents the average character of the entire day's run. More extended acquaintance with the stuff might lead me to modify somewhat the statements made. With this caution I state the following

CONCLUSIONS.

No practicable chemical treatment will purify the sewage to such an extent that it may be discharged into the lower Mystic lake with a reasonable expectation of freedom from offence.

It is *possible* to treat the sewage so that if it were discharged into a running stream, or into a tidal basin with considerable circulation, the risk of offence would be *very much lessened.*

The most practical way of treating the sewage would be to collect in tanks, mix with sulphuric acid (perhaps with addition of a small amount of sulphate of alumina), allow to settle, filter through coke or other material, and then pass the liquid over marble chips or broken limestone to the point of discharge.

The act of 1881, ordering the discontinuance of the sewer unless the sewage was so treated as to render it free from polluting substances, was the subject of a large amount of controversy between the city authorities of Boston and the authorities of the towns bordering on the lower Mystic lake. Finally, after the constitutionality of the Act had been affirmed by the courts, an injunction was issued, on the

petition of the town of Medford, to prevent any further discharge into the lower Mystic lake.

Thereupon the city proposed to construct works by which, through the operation of sedimentation supplemented by partial filtration through natural gravel beds, the larger portion of the suspended impurities of the sewage might be removed. This proposition was agreed to by the town of Medford, and the proposed works were constructed in the town of Winchester, near Bacon's crossing, upon an area of about 5.5 acres. At this point a dam was thrown across the sewer, and its contents lifted by a pump into a large settling tank, in which it was hoped that the heavier impurities would be deposited in such manner as to permit of their removal from time to time. The overflow was received into a ditch, 1,250 feet long, after flowing through which it again entered the sewer. During its passage through this long trench about one-third of the partially purified sewage was absorbed into the porous, gravelly soil in which the trench was dug. An additional amount of suspended impurities was also removed by means of brush dams placed at intervals across the trench.

The original works were found inadequate to the proper purification of the sewage, and in 1883 additional settling tanks were constructed on an improved pattern, and a new effluent ditch, about 1,400 feet in length, excavated between the tanks and the point where the sewage was returned to the main sewer.

An experiment was also made in 1884 with a Farquhar mechanical filter, which proved to be incapable of purifying a sewage carrying as large an amount of matter in suspension as this.

These various sedimentation and partial filtration processes having proven unsatisfactory, the Boston Water Board concluded in 1887 to adopt chemical precipitation, and accordingly detailed Wilbur F. Learned, C.E., to experiment and report on a scheme for treating the sewage by chemical methods. In a paper, Some Facts about the Chemical Treatment of the Mystic Sewage, which Mr. Learned read before the Boston Society of Civil Engineers in February, 1888, it is stated, in regard to the character of the sewage, that the morning flow is very much diluted with ground-water, but between 10 and 11 A.M., or thereabouts, the sewage gradually grows heavier, reaching its maximum density about 2 or 3 P.M. In the meantime its color has changed from that of dirty water in the morning to a brownish black in the afternoon, passing through the various shades of tan to very deep red and thence to almost black.

The total dissolved and suspended matter is stated as 112 grains per U. S. gallon in the morning, while in the afternoon a maximum is reached of 540 grains per U. S. gallon. The suspended matter

amounts to 16 grains per gallon in the morning and 128 grains in the afternoon. The sewage is generally neutral, though occasionally showing a slight alkaline reaction.

In regard to his experiments on the chemical treatment of this sewage, Mr. Learned says :

The chemical reagent used for precipitation was crude sulphate of alumina of two grades, called S. cake and B. cake. The S. cake contains 3 per cent. free sulphuric acid, 18 per cent. free alumina, and 40 per cent. sulphate of alumina. The B. cake contains .005 free sulphuric acid, 18 per cent. free alumina, 44 per cent. sulphate of alumina. The large quantity of free acid in the S. cake soon destroys any iron-work with which it may come in contact, and it is not therefore as preferable for a precipitant as the B. cake. The amount of precipitant used in the forenoon is always less, and with better results, than in the afternoon. For instance, a precipitant applied to the sewage between 9 and 11 o'clock A.M., at the rate of one-half ton per 1,000,000 gallons will throw down 25 per cent. of the total matter in the sewage, while two tons per 1,000,000 gallons applied to the sewage between 3 and 4 o'clock P.M. will not precipitate more than 30 per cent. of the total matter. I have seen the reagent at the rate of one ton per 1,000,000 throw down 31 per cent. of the total matter, and with the same sewage a treatment at the rate of two tons per 1,000,000 gallons throw down only 32 per cent. of matter.

Such results seem to show that beyond certain limits the chemicals precipitate a small amount of matter.

The coarse suspended matter is easily precipitated by a moderate amount of the chemical reagent, and some of the finer particles are also thrown down, whereby the effluent is deprived of some of its color, and a corresponding portion of the offensive matter removed ; besides this, there is dissolved matter which seemingly undergoes little change in the presence of the chemical reagent.

The quantity of precipitant recommended for the Mystic sewage is 1.75 tons of crude sulphate of alumina per 1,000,000 gallons, and increasing gradually until the amount reaches 3 tons per 1,000,000 between 2 and 4 o'clock P.M., then decreasing as the sewage becomes less dense to the rate of half a ton per 1,000,000 at midnight. With this quantity for a precipitant, it is believed that the effluent will be clear and tolerably free of color, the suspended matter all thrown down, and as much of the dissolved matter as may be consistent with a single reagent.

Should, however, additional purification be required, an increased reagent will not give better results ; but if the effluent, having all the suspended matter removed, and in a state of comparative purity, be run on to land of a gravelly nature, which will act as a *chemical* filter, a still further state of purity will be obtained.

Velocity of treated sewage.—One of the experiments was made with sewage clarified by subsidence and subsequently treated, thus forming a large quantity of fine flocculent matter which required a long time for precipitation.

The velocity of the treated sewage in the precipitation tanks varied from 0.33 foot per minute to 0.70 foot per minute. In a few instances definite quantities of suspended matter in the effluent were obtained, while in other cases when the velocity was greater no results were obtained. For instance, in one case, when the velocity was 0.56 foot per minute, 23 grains per gallon were obtained, and in another, when the velocity was 0.37 foot per minute, 16 grains per gallon were found, while in cases when the velocity was 0.70 foot per minute no results were obtained.

It should be borne in mind that the precipitation tanks were inadequate for the purpose of precipitation.

If they had been twice as long, in order to give the flocculent matter ample time to precipitate, I have no doubt that a velocity of 0.50 foot per minute would have given a very fine effluent, free of suspended flocculent matter.

Treatment of crude sewage and of clarified sewage.—This experiment consisted in treating crude and clarified sewage with equal quantities of precipitant at different hours of the day.

The total average per cent. of matter precipitated from the crude sewage was 29 per cent., and the amount precipitated from the clarified sewage was 30 per cent.

This small difference might have been increased somewhat by a greater number of trials, but the difference will always be small when the amount of reagent applied to the crude sewage is adequate, because it requires a large quantity of precipitant to throw down the fine particles of matter in the clarified sewage, while the same quantity applied to the crude sewage will give very nearly as good results.

Admitting a slight advantage by treating the clarified sewage when the amount of precipitate alone is considered, the advantages obtained from the crude sewage, such as compact sludge, active precipitation, etc., far exceed that of the former method.

The benefit of having a compact sludge cannot be too highly spoken of; in fact, lime is frequently added as a reagent in part for this purpose, and is one of the requirements in case the sludge is to be pressed.

As the result of his experiments, Mr. Learned recommended the following for the Mystic valley sewage:

(1) The intermittent treatment of the sewage.

(2) The construction of four precipitation tanks, each capable of holding three hours' pumping.

(3) A sludge-well into which the sludge may be drained.

(4) A sludge-pump for raising the sludge into flumes, by which it may be conveyed to shallow basins for partial desiccation until such time as pressing the sludge may become a necessity.

(5) A branch sewer from the present line of main sewer to a pump-well on the city's land.

(6) An engine and pump for pumping the sewage into the tanks.

(7) Tanks and machinery to aid the dissolving of the crude sulphate of alumina.

(8) Buildings, including engine-house, coal-shed, etc., all at an estimated cost of $11,000.

In accordance with this recommendation the present works, which are illustrated in Figs. 57, 58, and 59, were designed and constructed, ready for operation, in the latter part of the year 1888. They consist, in detail, of a pump-well connected with the main sewer by a branch sewer of brick, a sewage-pump and engine, engine-house, four settling tanks, a sludge-well, sludge-pump, and a series of settling basins for receiving the sludge. The general design of the works may be readily inferred from the illustrations. In the engine-house are three vats (marked chemical tanks on the plan), so arranged that the precipitant is fed from the middle vat, which is placed lower than the other two, in which the precipitant is dissolved; these vats are provided with steam coils for heating the water used, and with a stirring apparatus driven by the engine.

The precipitant is fed to the sewage as it flows from the branch sewer into the pump-well; the process of pumping thoroughly incorporates the chemicals. As each settling tank is filled, the sewage is allowed to remain quiescent for about three hours, after which time it is found that the sedimentation process is complete. The clarified

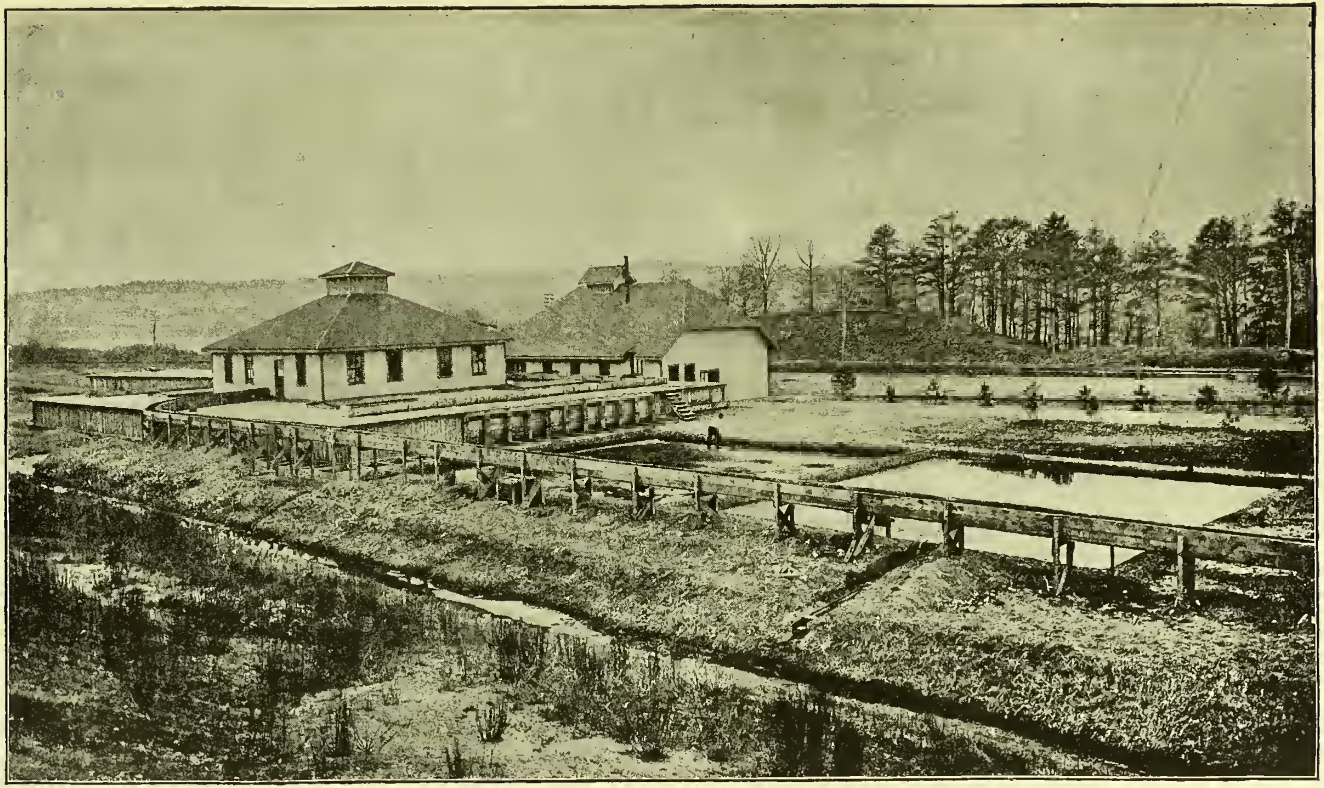


FIG. 57.—GENERAL VIEW OF MYSTIC VALLEY SEWAGE DISPOSAL WORKS.

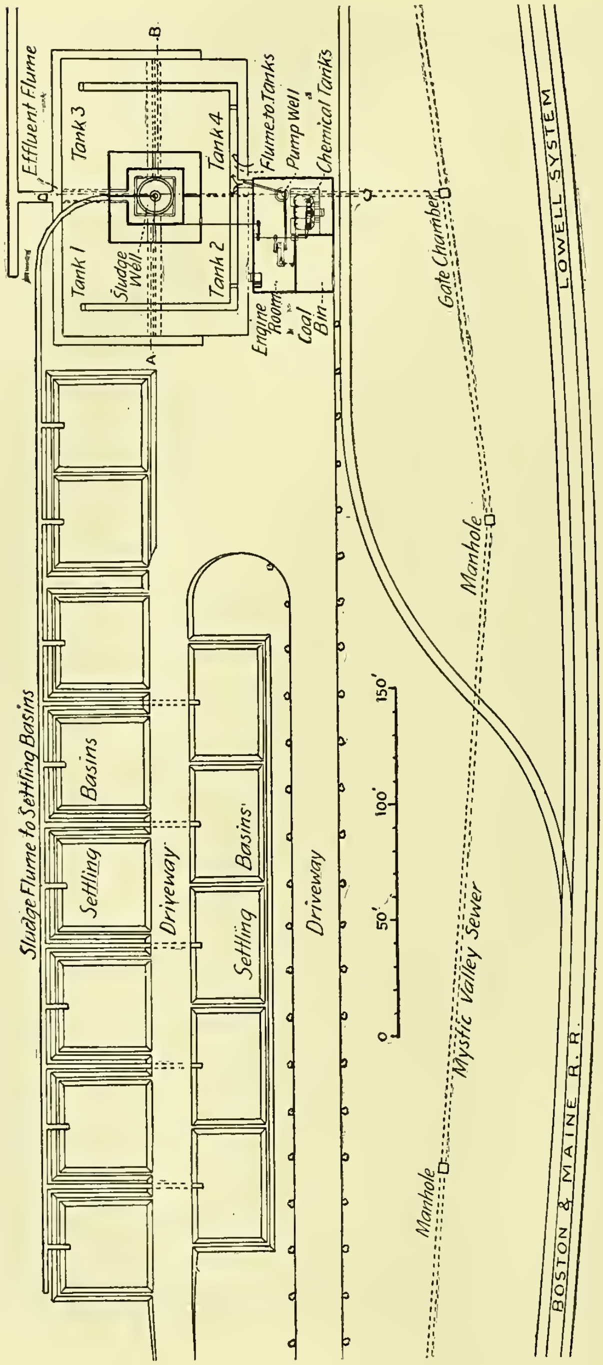


Fig. 58.—General Plan of Mystic Valley Sewage Disposal Works.

effluent is then drawn off by means of narrow stop-planks, which are removed one by one. During the winter season the tanks can be filled six times before it is necessary to remove the sludge. In warm weather the sludge, if allowed to remain too long, is liable to become offensive, and it is necessary to remove it somewhat oftener. The removal is effected through sluices connecting with the sludge-well, which is placed in the middle space between the four tanks, as indicated on the plan, Fig. 58. From the sludge-well the sludge is pumped into a flume, which conveys it to the settling basins. A cross-section through the buildings, on the line C D on the plan, is shown by Fig. 59. The results of a number of measurements, made since the plant was put in operation, show that on the average 1 volume of sludge is deposited to every 30 volumes of sewage treated. After the effluent has been drawn down as low as it can be without disturbing the sludge, the latter is found to contain about 4 parts of dry solids to 96 parts of water; a large portion of the water disappears in the settling basins, leaving a product sufficiently dry to permit of handling, and containing about 4 parts of solids to 12 parts of water. The volume of the dry product is in the neighborhood of 10 cubic yards daily.

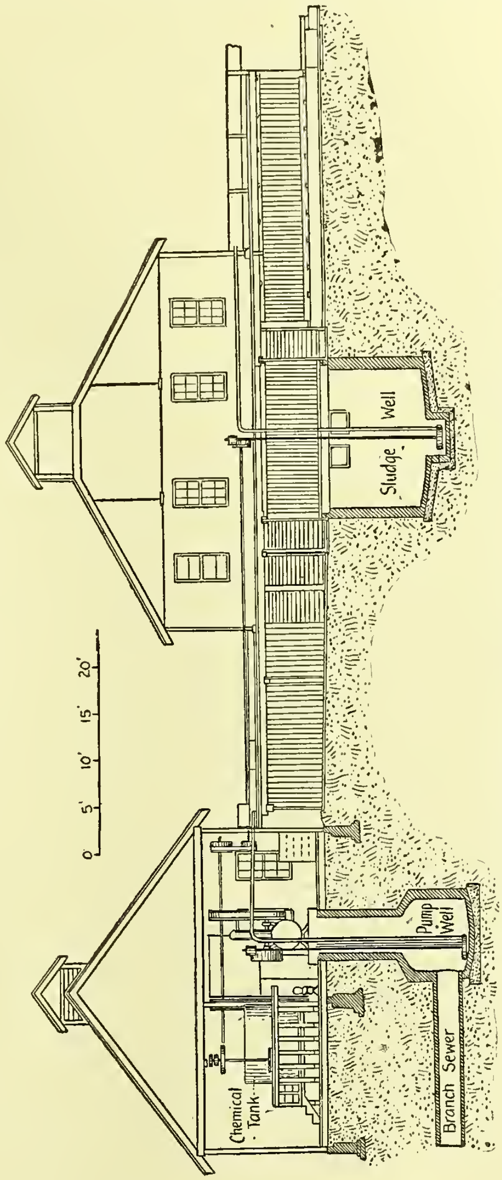


Fig. 59.—Cross-section through Mystic Valley Disposal Works.

The cost of the present works, including the preparation of the settling basins, was $10,410.

For the year ending December 31, 1889, the total amount of sewage pumped and treated was 99,882,850 gallons, or 324,000 gallons per day, exclusive of Sundays and legal holidays, when the pumps were not run; 404,270 pounds of sulphate of alumina were used as a precipitant, and 162 tons of coal used in the pumping.

The cost of pumping and treating the sewage, exclusive of the care of the main sewer and its branches, is given as $152.46 per 1,000,000 gallons treated.

For the year ending December 31, 1890, the pumps ran 335 days, working 5,147 hours, and the amount of sewage pumped and treated was 119,119,670 gallons, making an average of 355,500 gallons per day of pumping. The total amount of sulphate of alumina used during the year was 323,650 pounds. The coal consumption amounted to 191 tons. The quantity of sludge removed from the basins was 2,611 cubic yards.

The rate of precipitant used for the year 1890 was 1 part of crude sulphate of alumina to 3,067 parts of sewage, or 1.36 net tons per 1,000,000 gallons of sewage.

For the 13 months ending January 31, 1892, the total quantity of sewage pumped and treated was 133,102,028 gallons. The total amount of crude sulphate of alumina used was 331,890 pounds; the amount of coal, 210.66 tons.

The quantity of sludge removed from the basins was 2,334 cubic yards, the most of which was carted away by a neighboring farmer, and used as a fertilizer. The rate of application of precipitant was one part to 3,354 parts of sewage, or 1.24 net tons per 1,000,000 gallons of sewage.*

* The sources of information in regard to the Mystic Valley Sewage Disposal Works are the 2d, 5th, 6th, 8th, 12th, 13th, 14th, 15th, and 16th An. Repts. of the Boston Water Board; and Mr. Learned's paper, Some Facts about the Chemical Treatment of Mystic Sewage, in the Jour. Assoc. of Eng. Socs., vol. vii., No. 7 (June, 1888), pp. 244–248. Mr. Learned's paper is also to be found in Eng. & Bldg. Recd., vol. xix. (1889), p. 189.

CHAPTER XXVII.

CHEMICAL PRECIPITATION AT WORCESTER, MASSACHUSETTS.

Probably the sewage disposal of the city of Worcester, Massachusetts, has been the subject of more discussion than that of any other American city. As long ago as 1872, Phinehas Ball, C.E., presented a scheme for the utilization of the Worcester sewage; and the Massachusetts State Board of Health, at the very beginning of its series of studies of river pollution, selected the Blackstone river, which receives the sewage of Worcester, as one of the streams for special examination. The results of this original study of the Blackstone river by the State Board of Health are to be found in its Fourth Annual Report. The examination of the waters of the river, which was thus begun in 1872, was continued in the following year, and the additional results may be found in the Fifth Annual Report of the Board. In the Seventh Annual Report may be found further investigations, and a statement in detail of all the various sources of pollution which existed on the Blackstone river at that time, together with analyses of the water, and a tabulation of the dry weather flow in relation to the sources of pollution, number of the same, etc., per square mile. From the summary it appears that there were at that time 44 woollen mills, employing 3,003 operatives; 27 cotton mills, employing 3,978 operatives; 12 iron works, employing 1,224 operatives; 1 tannery, employing 6; and 1 shamble, employing 5 operatives. The sewage and various manufacturing wastes of nearly all those establishments passed directly into the river. In the Fourth Annual Report of the State Board of Health is also given an extended series of analyses of samples of the sewage of Worcester, made by Professor Wm. Ripley Nichols, from which it appears that the average day sewage of Worcester contained at that time 25.35 parts in 100,000 of total dissolved matters, 1.876 parts of free ammonia, and 0.316 part of albuminoid ammonia. The average night sewage contained 15.29 parts in 100,000 of total dissolved matters, 0.745 part of free ammonia, and 0.144 part of albuminoid ammonia.

In order to understand the relation of the City of Worcester to the Blackstone river, it should be stated that the river is formed by the confluence of the Kettle and Mill brooks, in the southern part of the city of Worcester, and flows thence in a southeasterly direction to tidewater at Pawtucket, Rhode Island, crossing the state line at Black-

stone. The drainage area of the Blackstone in Massachusetts, not including Mill river, which unites with it below the state line, is 260 square miles.

The valleys of the two streams, which unite at Worcester to form the Blackstone river, contain naturally a number of small lakes and ponds. These streams are rapid flowing, and, as on the other tributaries of the Blackstone, nearly every available mill site in the valleys has been utilized for the location of mills. In order to supply water power during the dry season, many of the natural bodies of water have been converted into storage reservoirs by the construction of dikes and embankments, and in addition many large artificial storage reservoirs have been built. From this complete development of the water power in the valleys it results that the dry-weather flow of the streams is kept high by the flow of the large amount of stored water. The mills, however, discharge into the stream, as already stated, much of their sewage and manufacturing wastes, which are nevertheless more thoroughly diluted and removed than they otherwise would be, by reason of the large dry-weather flow due to storage.

The city of Worcester is supplied with water from the head waters of the Blackstone river. In 1892 the sewerage system included about 80 miles of sewers which discharge sewage into the river, chiefly through Mill brook, one of the confluent tributaries. An Act was passed by the Massachusetts Legislature in 1867 allowing Mill brook to be used as a common sewer. Since that time it has been walled in and arched over for much of its length through the city, so that it has become, substantially, a main sewer of the city.

The population of Worcester, by the census of 1890, was 84,645, and the growth during the previous 25 years is shown by the following figures:

In 1865 the population was 30,047; in 1870, 41,105; in 1875, 49,317; in 1880, 58,291; in 1885, 68,383.

The daily consumption of water is stated as amounting to 4,635,000 gallons in 1890. In 1892 it may be taken at about 5,000,000 gallons per day, giving for a population of 90,000 an average per capita of 55.5 gallons per day.

The distance by river from Worcester to Blackstone, at the state line, is 26 miles, and the fall in that distance is 220 feet, and throughout this whole distance are located a large number of manufacturing establishments.

The Blackstone river is not used at any point for a public water supply, and the chief reason for a demand on the part of the riparian owners below Worcester for the purification of the sewage of that city, was the production of a nuisance so serious as not only to unfit the water of the stream for use in manufacturing operations, but also be-

cause of its condition being probably dangerous to health. The physicians practising in the towns below Worcester, through which the river flows, for a number of years considered the conditions such as to produce a large amount of sickness.

In regard to the effect of the sewage contamination upon the use of the river water for manufacturing purposes, it was claimed that light-colored cloths could not be made when the river water was used, and that some of the cotton mills were obliged to give up the making of this class of goods. The water was also found unfit for use in steam boilers, causing foaming and corrosion. Statements made by manufacturers along the river indicated that this trouble was met with at all the mills where water from the river was used in steam boilers, while those using the water of tributary streams did not have this cause for complaint. The reason for this condition of the river water was probably found in the fact that a number of the manufacturing establishments at Worcester discharged a large amount of waste acid into the stream. This was particularly the case with the sewage from the wire works which are located there.

As regards the discharge of crude sewage into the Blackstone river, the effect upon the city of Worcester itself has not been at any time specially unsatisfactory, except that the foul smells in Mill brook have necessitated, as already stated, the covering of that stream within the city limits. The nuisance, however, gradually became very serious to the people on the banks of the river below Worcester, and was especially offensive at Millbury, which is the nearest town to Worcester.*

Having indicated in the foregoing the conditions which led to a demand on the part of the people living upon the banks and using the waters of the Blackstone river below Worcester, for a purification of the Worcester sewage, we may, before describing the works which have been actually carried out, refer to the several projects at different times proposed. The first of these, as already noted, is Mr. Ball's, of 1872. Mr. Ball's report is given in the Fourth Annual Report of the State Board of Health, page 109 and following, and the map accompanying it may be found facing page 406 in the Seventh Annual Report of the same Board. From them it appears that Mr. Ball proposed in 1872 to dispose of the sewage of the city by irrigation, at a point about three miles below the city and not far from the village of Millbury. The project involved the delivery of the sewage to this area by gravity.

In 1881 the town of Millbury employed Col. George E. Waring, Jr., "to suggest some practicable plan by which the city of Worcester

* For a discussion of the process of self-purification as exemplified in the case of the Blackstone river, see Special Report of the Mass. St. Bd. Health, Part I., Examination of Water Supplies, pp. 794–798.

may withhold from the Blackstone river the waste organic matter produced by the population and its industries, and now polluting that stream."

The plan proposed by Col. Waring included the following:

I. To separate the dry-weather sewage of the city and the early storm-washings of the sewers from the water of Mill brook.

II. To allow the earthy matters of the sewage to subside.

III. To screen out the coarser objects.

IV. To expose the screened sewage in a thin sheet to the air during its rapid flow for a distance of 500 feet at a sharp fall.

V. To carry it at low velocity for about 10 miles through ditches bordered by rank-growing trees or bushes; alternating to a second set of ditches as often as necessary, say once a week, so as to give each set a dry week for the aëration of the subsided matters.

VI. To spread the resultant effluent over 126 acres of wooded swamp land, giving each area two days out of three for aëration.

The area selected by Col. Waring is included in the area near Millbury, which Mr. Ball proposed to utilize in 1872.*

The Legislature of 1881 directed the State Board of Health to investigate the question of sewage disposal for Worcester, with special reference to preventing the further pollution of the Blackstone river and its tributaries, and recommend a definite plan for preventing such pollution. The Board appointed, as experts, C. F. Folsom, M.D., and Joseph P. Davis, M. Am. Soc. C.E., who, acting in conjunction with Dr. Walcott, Secretary of the Board, designed a system of disposal by intermittent filtration. By this project the sewage would be diverted from Mill brook and conducted, partly by gravity and partly by pumping from a low area, to a tract of land midway between Worcester and Millbury, and in the vicinity of the locality previously selected by Mr. Ball and Col. Waring, but at a somewhat higher elevation. For this purpose it was proposed to distribute the sewage at a rate not exceeding 40,000 gallons per acre per day, the experts expressing the opinion that this daily quantity would not be large enough to prevent the successful raising of crops on the filtration area. The estimated cost of carrying out the plan of intermittent filtration was $408,490. The necessary pumping was estimated at $3,500 per year. The cost of construction under Col. Waring's plan was estimated at $206,500.

Criticisms of Col. Waring's plan are submitted by the experts in their report, and reasons given why, in their opinion, it would not provide an efficient solution of the sewage disposal problem for Worcester.†

* Col. Waring's report may be found in the Sanitary Appendix to the 3d An. Rept. of the Massachusetts State Board of Health, Lunacy, and Charity, for the year 1881.

† The experts' report may also be found in the Sanitary Appendix to the 3d An. Rept. of the State Board of Health, Lunacy, and Charity.

At the first session of the Legislature following the presentation of this report, a bill was introduced in the interests of the residents along the Blackstone river below Worcester, by the provisions of which the city of Worcester was required to purify its sewage before discharging it into the river, within four months from its passage, and thereafter to cease discharging into the river all matter offensive or dangerous to public health. In the extended hearing which was given before the Joint Standing Legislative Committee on Public Health, the riparian owners claimed that they were injured in health and business by reason of the presence of Worcester sewage in the stream. Testimony was given on the part of the petitioners for the bill to the effect that only a few years before, the stream was pure and fit for all kinds of manufacturing uses; whereas now the stream had become offensive to sight and smell, and its water rendered entirely unfit for use in manufacturing. The city authorities denied nearly all the statements of the petitioners, claiming in effect: (1) The city was not creating any nuisance; (2) even if the city were creating a nuisance, it still had a right to do so under the Law of 1867, by which it was permitted to discharge crude sewage into Mill brook; (3) the proper remedy for the petitioners was not to compel Worcester to purify its sewage, but to remove the dams built by the petitioners, thereby removing obstructions in the stream which prevented the sewage from flowing freely and purifying itself. The expert testimony on the side of the city was prepared by Wm. E. Worthen, M. Am. Soc. C.E., and the city engineer, Charles A. Allen, M. Am. Soc. C.E. The State's side of the case was presented by Drs. Folsom and Wolcott, and Joseph P. Davis, M. Am. Soc. C.E., who, as a commission of experts, had devised the project of disposal by intermittent filtration, already briefly described.*

The opposition on the part of the city to the compulsory expenditure of the large amount of money which was required to effect the purification, was sufficiently strong to prevent anything being done at that time, and the Legislature adjourned without passing the Act. The bill was again introduced at the session of 1884, and, after a spirited opposition on the part of the city, again defeated, for reasons similar to those which had been previously urged.

In his report to the Massachusetts Drainage Commission in 1885, Mr. Clarke further considers the question of sewage disposal for Worcester, and reviews the several reports which have been made previous to that time. His conclusion was that a solution of the problem of sewage disposal at Worcester had already been devised by the experts

* For this evidence in detail, see The Sewage of Worcester in its Relation to the Blackstone River. Hearing before the Joint Committee on Public Health, in the matter of restraining the city of Worcester from polluting the Blackstone river. Feb. and March, 1882, Pamphlet, 164 pages.

of the State Board of Health in 1881, and he therefore investigated the conditions at Worcester no further than was necessary to verify the essential features of their plans. Mr. Clarke states that an examination of the territory below Worcester showed that the tract of land which had been selected as a filtration area was most accessible and suitable for the purpose. Borings and test-pits also proved the adaptability of the soil for filtration.

The estimates prepared by the experts were verified by Mr. Clarke, with the result that if they were in error at all they were larger than necessary. Mr. Clarke closes the portion of his report treating of Worcester sewage disposal with the suggestion that the Drainage Commission could, with propriety and safety, recommend that Worcester be required to purify its sewage in some way; but that a choice of method and its details be determined by the city itself.

During the period of discussion the pollution increased from year to year, and in 1883 the City Council of Worcester directed the city engineer, Charles A. Allen, M. Am. Soc. C.E., to proceed to Europe in order to acquire a thorough knowledge of sewage disposal as practised there, with special reference to the conditions obtaining at Worcester. Mr. Allen accordingly visited England, France, and Germany, examining the methods of sewage disposal in use at Croydon, Doncaster, Burnley, Bradford, Leeds, Barnsley, Wigan, Leyton, Birmingham, and Atherton in England, Paris in France, and Berlin and Dantzic in Germany.

Finally, in 1886 the Legislature passed an Act directing that the city of Worcester should, without being limited to any particular system, within four years after its passage, remove from its sewage, before its discharge into the Blackstone river, "the offensive and polluting properties and substances therein, so that after its discharge into said river, either directly or through its tributaries, it shall not create a nuisance which might endanger the public health."

The city was also authorized by the Act to acquire rights of way or easements wherever needed for the construction of the necessary sewerage and sewage disposal works, and for the payment of all damages sustained by any person or corporation by reason of such erection or construction; also to raise and appropriate such sums of money as might be required to carry out the provisions of the Act.

September 20, 1886, the City Council ordered that the city engineer make such investigations, examinations, surveys, plans, and estimates, and take the opinions of such experts as he deemed necessary to ascertain the best and most approved system of sewage disposal to be obtained for the city of Worcester in compliance with the law. The city engineer was also directed to report his plans as soon as possible. In his report, submitted in accordance with this order, Mr. Allen first

gives an account of the several foreign sewage disposal works visited by him in 1883.

In regard to the disposal of the sewage of Worcester by irrigation, Mr. Allen says :

Now the conditions, climatic and other, that exist at Worcester are not as favorable to the proper treatment of sewage by irrigation or by filtration as in England and France, or even in Germany, at Berlin and Dantzic.

It has been stated, both in reports made upon the subject of sewage treatment and in evidence taken in support of the claim that the city of Worcester should purify its sewage, that the climate at Berlin and Dantzic, where broad irrigation is resorted to, is substantially the same as at Worcester, and that therefore it will be easy to purify the sewage of the city by irrigation throughout the entire year.

I think, however, that there is a reasonable doubt about this. The following statements of the difference in temperatures will show a decided difference in climatic conditions during the winter months. The temperatures at Dantzic were obtained from Mr. Aird, the manager of the farm at that place, and are official; while the temperatures at Worcester are taken from the city records.

The following table gives the differences in temperature for five winters, beginning with December 1, 1877, and ending March 31, 1883:

Dantzic.	Average monthly temperature.	Worcester.	Average monthly temperature.
December, 1878	34° Fahr.	December, 1878	25° Fahr.
January, 1879	28° “	January, 1879	20° “
February, “	32° “	February, “	20° “
March, “	33° “	March, “	30° “
Average by months ...	31.75° Fahr.	Average by months ...	23.75° Fahr.
December, 1879	27° Fahr.	December, 1879	28° Fahr.
January, 1880	29° “	January, 1880	30° “
February, “	31° “	February, “	27° “
March, “	36° “	March, “	29° “
Average by months ...	30.75° Fahr.	Average by months ...	28.5° Fahr.
December, 1880	34° Fahr.	December, 1880	20° Fahr.
January, 1881	23° “	January, 1881	16° “
February, “	28° “	February, “	23° “
March, “	34° “	March, “	32° “
Average by months ...	29.5° Fahr.	Average by months ...	22.75° Fahr.
December, 1881	34° Fahr.	December, 1881	33° Fahr.
January, 1882	37° “	January, 1882	21° “
February, “	38° “	February, “	25° “
March, “	44° “	March, “	32° “
Average by months ...	38.25° Fahr.	Average by months ...	27.75° Fahr.
December, 1882	26° Fahr.	December, 1882	23° Fahr.
January, 1883	27° “	January, 1883	18° “
February, “	30° “	February, “	22° “
March, “	26° “	March, “	23° “
Average by months ...	29.75° Fahr.	Average by months ...	21.5° Fahr.

It will be noticed that, with the exception of the winter of 1879–80, the mercury ranged much lower at Worcester than at Dantzic, a difference of from 7° to 8° Fahr.

for the entire season being the general amount. This, of course, makes a great difference in frost penetration, and adds to the liability of the ground remaining frozen.

An examination of the tables of daily temperature . . . shows that, in the five years covered by the tables given above, at Dantzic there were only three days during that period that the thermometer registered below zero, the extreme being 4° degrees below; while at Worcester, during the same period, there were forty days below zero, with an extreme of 18° below.

At Dantzic there were thirty-eight days in which the temperature was between 10° and 20° above zero, while at Worcester there were 164 days.

While there were 364 days at Dantzic in which the thermometer registered between 20° and 32° degrees above, at Worcester there were 221 days.

The total number of days covered by the observations in the five years was 606. Of this number Dantzic had 460 below the freezing point, or about 75.9 per cent., while Worcester had 542 days, or 89.4 per cent.

While Dantzic had only 114 days below 20°, or 18.8 per cent., Worcester had 328, or 54.1 per cent.*

As has been stated in the description of the works at Berlin, the sewage is stored in large reservoirs during the severest portion of the winter, no attempt being made to purify by irrigation; while at Dantzic it is constantly applied to the land without regard to the weather, the manager stating that while the action of the frost interfered somewhat with the operation of the works, still the periods of extreme cold were of so short duration that no serious difficulty was experienced.

A glance at the table of temperature will illustrate this fact. For instance, from the 25th to the 28th inclusive of January, 1881, was the coldest weather indicated for any four consecutive days in the five years. For the following twenty days the temperature averaged 33°, one degree above the freezing point, so that whatever frost had penetrated the ground during the short cold period would undoubtedly be removed long before the twenty days had expired. In fact, there could have been very little severe frost after this time, for the average temperature of the month of February following was 28° Fahr., while March had an average of 34° Fahr.

It is true that here in New England extremes of cold are followed frequently by warmer periods—that is, the weather is not excessively cold for long periods of time; but the reaction is not generally great, and it is almost too well known a fact to be commented upon, that after the frost once enters the ground here, it stays with almost constantly increasing depth until spring fairly opens.

That this difference in climatic conditions is likely to prove a troublesome matter, if any method of land treatment is exclusively relied upon, there would seem to be but little doubt.

In Mr. Allen's opinion the climatic difficulty at Worcester was likely to be a serious one, and he accordingly deemed it desirable to take the opinion of some of the ablest English sanitary engineers upon this point. In response to a request from him, Mr. B. S. Brundell, M. Inst. C.E., who has constructed many sewage farms, among them the farm at Doncaster, England, which is one of the most successful (from a sanitary point of view), wrote as follows:

Sewage if properly applied to land may be purified; but the operation is not profitable. That is to say, sewage farming cannot, save in exceptional instances, be made to pay. Given a sufficient and suitable area of land, and if the sewage is passed either over or through it you can have an effluent water fit to pass into any

* For complete table of comparative daily temperatures at Worcester and Dantzic for the five winters, 1878–79 to 1882–83 inclusive, see either the Appendix to Mr. Allen's original report, or his paper on Sewage Disposal, in Trans. Am. Soc. C.E., vol. xviii., pp. 16–17.

Also refer to table on page 306 for mean temperature of winter months at Dantzic for 81 years.

stream without polluting that stream. Whether what is known as sewage farming could be made to succeed in your climate it is almost impossible to say.

With a winter of extreme severity extending, as you say, from early in November to April, and with the ground frozen from three to five feet deep for a good part of that time, the application of sewage would be extremely difficult.

Our winters here, although adding to the trouble of sewage irrigation, do not make it impossible. The temperature of the sewage when it reaches the land is sufficiently high to keep the *outfalls* open; but of course when it spreads upon the land it soon becomes frozen, and remains a glazed surface until the thaw sets in, when it is gradually absorbed by the land.

I do not feel able to give an opinion as to how far this process would be limited by the degree of cold to which you are liable, but I foresee very considerable difficulty in the matter.

Mr. James Mansergh, M. Inst. C.E., in answer to a similar inquiry addressed to him, wrote as follows:

I have carefully considered, in the light of my experience in England, whether under such conditions as these, the disposal of sewage by way of broad irrigation and downward intermittent filtration may be counted on as a reliable and satisfactory mode of treatment.

My experience on this matter dates from the year 1860, when, in conjunction with my then partner, Mr. Hugh U. McKie, C.E., City Surveyor of Carlisle, I laid out the first sewage farm ever made in England, to Mr. McKie being due the credit of its suggestion and initiation.

Since that time, I have laid out the following sewage farms:—Bedford, Tunbridge Wells—with *two* farms, Colney Hatch, Leavesden, and Caterham Metropolitan Lunatic Asylum, Lincoln County Asylum, Ormskirk, Reading, Grantham, Southborough, Lincoln, St. Albans, Chesham, Bethesda, and Burton-upon-Trent (now in hand), and I have advised upon Ashford, Hildenborough, Rotherham, Birmingham, Hereford, Staines, Waltham, etc., etc.

I believe my practice in this branch of engineering is not second to that of any man in England.

During my connection with these works, and on my visits to other sewage farms, I made myself acquainted with the circumstances of the application of sewage to land during our English winters, and since my interviews with yourself I have made special and particular inquiries at several of the farms above mentioned.

The general experience in England undoubtedly is that with ordinary care no real difficulty is experienced in getting rid of sewage during frosty weather.

This, I think, may be accepted as a fact. At the same time, I have myself seen ice six or eight inches thick on a sewage farm with a clay subsoil, and the sewage continuing to freeze on the surface; and I have heard that, in the severe winters we have had here since 1878, it has been with some difficulty that trouble has been avoided on more than one farm.

It is palpable that the risks are greater where sewage is put upon clay lands than where the subsoil is an open or loamy gravel.

If the land can be kept unfrozen on the surface by the continuous application of the relatively warm sewage, all goes well.

A thin coating of ice may be formed during the nights, but the sewage can, as a rule, be readily distributed under this film.

In this country we rarely have long spells of hard frost unbroken by short intervals of heightened temperature.

Under the conditions you have described to me, I should have very great hesitation in recommending the process of broad irrigation and intermittent filtration as reliable modes of disposing of the sewage and preventing the pollution of the river.

I should fear that during such frosts as you tell me not unfrequently prevail, the ground would get frozen so hard as to render it impervious to the sewage, which would then simply flow over the surface into the river or its tributaries in a crude condition.

In order to acquaint myself more particularly with the relative temperatures at

Worcester, U. S., and England, I have obtained certain statistics from Mr. G. W. Symonds, F.R.S., which I have embodied in the accompanying diagram.*

In addition to Worcester and London, all the facts are given with accuracy in respect of Vienna and so far as concerns the "mean" in respect of Berlin, but the "minimum" of Berlin is merely the best approximation I can just now procure.

From this diagram I learn that, speaking broadly, the "mean" temperature of the months from November to March in Worcester and London compare as follows:

November,	Worcester	3°	Fahr.	lower	than	London.
December,	"	12°	"	"	"	"
January,	"	15°	"	"	"	"
February,	"	15°	"	"	"	"
March,	"	9°	"	"	"	"

The lowest recorded temperatures compare as follows:

November,	Worcester	10°	Fahr.	lower	than	London.
December,	"	10°	"	"	"	"
January,	"	21°	"	"	"	"
February,	"	34°	"	"	"	"
March,	"	21°	"	"	"	"

Making the comparison between the mean monthly temperatures of Worcester and Berlin (the sewage works of which city you have seen) the figures come out as follows:

November,	Worcester	1°	Fahr.	lower	than	Berlin.
December,	"	8°	"	"	"	"
January,	"	4°	"	"	"	"
February,	"	6°	"	"	"	"
March,	"	5°	"	"	"	"

I find from the diagram that the mean temperatures of Worcester are as follows:

November,	7°	Fahr.	above	freezing	point.
December,	5°	"	below	"	"
January,	8°	"	"	"	"
February,	7°	"	"	"	"
March,	1°	"	above	"	"

and the minimum temperatures are as follows:

October,	6°	Fahr.	below	freezing	point.
November,	20°	"	"	"	"
December,	35°	"	"	"	"
January,	46°	"	"	"	"
February,	51°	"	"	"	"
March,	32°	"	"	"	"
April,	10°	"	"	"	"

All these figures confirm me in my opinion that it would not be prudent to trust to getting rid of sewage satisfactorily at Worcester by the irrigation process.†

Continuing the discussion of objections to broad irrigation and intermittent filtration, in their application to the conditions obtaining at Worcester, Mr. Allen says:

The great difference in the amount of annual rainfall is also an important factor to be considered. The greatest rainfall given at any place visited was at Wigan, where the average is about forty inches per annum, while the smallest amount was at Barnsley, where the average was given as $28\frac{6}{10}$ inches per annum. The average of all places visited was 34 inches per annum.

At Worcester the average is about 48 inches per annum, the lowest recorded amount for one year being 34.5 inches (or about the same as the *average* amount at the places where inquiry was made), while the greatest recorded rainfall for one year at Worcester is 61.48 inches.

Now it is generally the experience abroad that during storms the sewage has to

* The diagram is not given in Mr. Allen's report.

† For further definition of the limitations of irrigation in winter, see Chapter XVII.

be disposed of in some other way than by irrigation, the ground being frequently surcharged with water, rendering it incapable of purifying the sewage at all. With the large rainfall here, this difficulty would be very much increased.

Aside from the difficulties caused by climatic differences, there is still another objection to irrigation that in the case of the city of Worcester should, it seems to me, have great weight. I refer to the loss of water by this means of sewage disposal. Just what the amount would be that the vegetation would absorb, and that would evaporate, can only be determined by actual trial.

At Berlin, the experiments show that at least 30 per cent. is retained, while at Doncaster most of the water is lost in this way, the reason being that only a small quantity of sewage is applied to any one piece of land, the intention being not to apply more than would come in an ordinary rainfall. That the loss of water would be considerable there can be no doubt.

For this, it is reasonable to suppose, the city would have to pay, as it is situated at the head of a manufacturing stream, where great value is placed upon every drop of water retained by any means, judging from the suits that have been brought against the city for water taken for domestic and general water supply purposes.

That this claim will be made, the following quotation will show. It is taken from the "Report of Millbury," dated Dec. 15th, 1881, and printed in connection with the report of the State Board of Health, Lunacy, and Charity, 1882:

"At this time, permit us to refer to a matter which we think ought not to be lost sight of in this connection. Whatever plan may eventually be adopted, there will necessarily result a greater or less loss of water, which, in the dry season of the year, when evaporation takes place rapidly, may amount to so much as to be a serious matter to the mills using the stream for water power. Even now the loss to manufacturers is noticeable. But it is claimed that whatever water is taken for the Worcester water supply is returned to the river through the sewers. This can, of course, be true only to a certain extent. With the sewer water used for irrigation and restrained for purposes of purification, the loss will be much greater.

"We should urge the necessity of providing some means to make good this loss. And we respectfully ask that, should your Board report to the Legislature a plan to prevent the pollution of the river, they will also report that, by means of additional storage basins to be used for this purpose, the city should make good the consequent loss of water."

This report was signed by George A. Flagg, C. D. Morse, and Osgood H. Waters, Committee of the Town of Millbury.

While they do not ask to be paid for water lost, they do ask that compensating reservoirs may be constructed, which amounts to about the same thing.

The above are the principal objections to irrigation so far as the city of Worcester is concerned. While they are more or less local in their character, there is danger that by the adoption of irrigation, especially when a large quantity of sewage is to be treated, the irrigation fields will become a greater nuisance than the one which is to be abated. In other words, it takes the most careful management to prevent a sewage farm from becoming offensive.

. . . .

What has been said in relation to the adoption of a scheme for treating the sewage of Worcester by irrigation, applies also to intermittent downward filtration, so far as the effect of the climatic and other conditions are concerned; in some respects, however, not to so great an extent. For instance, the amount of water lost by evaporation and absorption would not be as great. The effect of severe frosts would probably be about the same, as in order to obtain an effluent that is at all satisfactory, the application (as the name of the system implies) *must* be intermittent. It will not do to simply turn the sewage constantly over a single area of underdrained land, and expect that a clear effluent will be obtained: *the land must have rest.* "The intermittency is a *sine qua non*, even in suitably constituted soils, whenever complete success is aimed at." The danger would be that after one filtration area has received all the sewage that can be applied at one time, and before the relatively warm sewage can be again applied (generally after three or four

days), the ground would be frozen to such an extent that filtration would not take place.

The temperature of the sewage has therefore much to do with the length of time that the ground can be kept open, and also with the extent of the area upon which sewage can be applied in cold weather. There were only two places that I visited where a record had been kept of the temperature of the sewage, viz., at Berlin and Paris. At the former place the lowest temperature reached in winter was 45° F., while at the latter place the minimum was 41° F.

. . . .

At Worcester the sewers have all been constructed to receive drainage of every nature. All surface water is conducted to them, and in consequence the temperature of the sewage is at times very low. The record shows that in the main lateral sewers as low as 33° F. is reached. It is probable, therefore, that sewage taken from them and applied to the land would freeze quickly, and could not be depended upon to keep the ground free from frost.

The advantage that intermittent filtration would have over broad irrigation is that a much smaller area of land would be required, and the raising of crops would have to be made of secondary importance. In fact, it would be much better not to attempt to raise crops at all, as the income derived therefrom would be small, and the tendency would probably be to neglect the purification of the sewage in order to derive as large an income as possible from the land.

It must be understood that in order to obtain a good effluent, especially when the area of land is limited, some means of separating the sludge from the sewage is almost absolutely necessary to prevent the ground from clogging. This fact is recognized by English authorities and, as before shown, this method of sewage treatment is rarely used except as an auxiliary to irrigation or precipitation.

Chemical precipitation would not be subject to the objections spoken of above, and where the sewage has to be treated constantly, through the entire year, would seem to be the most favorable method for adoption at Worcester.

On account of the peculiar quality of the Worcester sewage, due to the character of the manufacturing wastes, it was considered desirable, before actually deciding to use the method of chemical purification, to obtain some idea of the probable amount of chemicals which would be required in order to produce a satisfactory effluent. Professor L. P. Kinnicutt, of the Worcester Free Institute, was requested to make a series of analyses, and give an opinion as to the quantity and quality of precipitating reagent best suited to the conditions. The following is from his report:

As to the chemical character of Worcester sewage a few words are necessary. Worcester sewage, in consequence of the nature and character of its manufacturing interests, contains, as may be seen from tables given below, a very large amount of soluble sulphates. It is well known that sea water cannot be used for flushing sewers, nor can sewage be run into the sea near the shore without a dreadful stink resulting. The cause of this stink is that the organic matter reduces the sulphates contained in the sea water to the state of sulphides, which are then acted upon by the carbonic acid, and sulphuretted hydrogen is set free. That these reactions would take place if Worcester sewage was treated according to either of the first two methods mentioned, seems to me more than probable. The sulphates in the sewage would be reduced to sulphides, and not only carbonic acid but the free acid in the sewage would immediately decompose these sulphides, and sulphuretted hydrogen, with its disgusting odor, would be continually given off.

The amount of *iron salts* contained in Worcester sewage is also large. Salts of iron are decomposed by alkaline substances, an insoluble hydrate of iron being formed, which attracts to itself the suspended matter in the sewage and carries it

to the bottom. In purification of sewage by precipitation, iron salts are commonly added after the sewage has been made decidedly alkaline by the addition of lime. The presence of these iron salts, therefore, would be an advantage in any precipitation process, while they would be more or less detrimental in an irrigation or intermittent filtration process.

. . . .

The second part of your question, What chemicals and what amount of chemicals are necessary to add to Worcester sewage, so as to produce an effluent which would be harmless when emptied into the Blackstone river? I find difficult to answer fully at this time. The answer to the question depends on the character of the sewage; what substances and what amount of these substances are contained in the sewage. To determine this a series of careful analyses made on samples collected at half-hour intervals during a number of days is necessary, the sewage being at the time of collection the normal dry-weather sewage. The last part of the above condition could not be fulfilled, as the flow of Mill brook at Cambridge street for twenty-four hours is at present about seventeen million gallons, which would not be the case if its flow depended entirely on the sewage received from the city.

Such being the case, I have not thought it best to make a long series of analyses, as I should like to have done, and have only made four analyses, two of day and two of night sewage. Each day and night sample was obtained by uniting half-hour samples taken throughout the twelve hours from Mill brook at Cambridge street. Table No. 1 gives the results of the analyses in parts per 100,000.

Table No. 2 gives the number of parts per 100,000 if the total amount of solid matter in the sewage remained the same, while the flow, instead of being 17,370,000 gallons, was reduced to the normal dry-weather flow of about 3,500,000 gallons; and also gives, for the sake of comparison, the mean of 181 analyses of London sewage, as given by Mr. Dibden in the Report of the Royal Commission on Metropolitan Sewage Discharge, Vol. 2, Page 158.

Table No. 3, columns 1, 2, and 3, give the total number of pounds of the various ingredients contained in twenty-four hours' flow of Mill brook at Cambridge street; and column 4 gives the calculated number of pounds that would be found in twenty-four hours in 1,000,000 gallons if the total amount of solids remained the same, while the flow, instead of being 17,370,000, was 3,500,000, or, in other words, gives an approximate idea of the amount of the various ingredients in 1,000,000 gallons of Worcester's dry-weather sewage.

Table No. 1.—Analyses of Worcester Sewage. Parts per 100,000.

January 14th and 15th.

	6 A.M. to 6 P.M.		6 P.M. to 6 A.M.		Average.	
Total solids	43.42	43.42	29.45	29.45	36.43	36.43
Volatile	14.72		7.82		11.27	
Inorganic	28.70		21.63		25.16	
Suspended		9.92		6.15		8.03
Soluble	33.50	33.50	23.30	23.30	28.40	28.40
Volatile	9.50		3.90		6.70	
Inorganic	24.00		19.40		21.70	
Chlorine	4.375		2.58		3.477	
Sulphur trioxide	8.104		6.07		7.086	
Nitric acid	trace		trace		trace	
Ferrous oxide	3.130		2.783		2.956	
Free ammonia	0.554		0.377		0.465	
Albuminoid ammonia	0.178		0.105		0.141	
Free acid, in terms of sulphuric acid	3.611		3.680		3.645	

January 18th and 19th.

	9 A.M. to 9 P.M.		9 P.M. to 9 A.M.		Average.	
Total solids	48.40	48.40	21.60	21.60	35.00	35.00
Volatile	20.77		6.10		13.43	
Inorganic	27.63		15.50		21.57	
Suspended		16.00		4.10		10.05
Soluble	32.40	32.40	17.50	17.50	24.95	24.95
Volatile	10.40		3.50		6.95	
Inorganic	22.00		14.00		18.00	
Chlorine	4.017		2.25		3.133	
Sulphur trioxide	8.113		3.917		6.015	
Nitric acid	trace		trace		trace	
Ferrous oxide	3.121		2.018		2.571	
Free ammonia	0.780		0.274		0.527	
Albuminoid ammonia	0.266		0.066		0.166	
Free acid, in terms of sulphuric acid	5.091		2.74		3.91	

TABLE No. 2.

Column 1. Parts per 100,000, mean value of four analyses if total amount of solid matter in the sewage remained the same, while flow was reduced to 3,500,000 gallons. Column 2. Mean of 181 analyses of London sewage.

	No. 1.		No. 2.	
Total solids	177.2	177.2	123.83	123.83
Volatile	61.3		45.50	
Inorganic	115.9		78.33	
Suspended		44.8		39.13
Soluble	132.4	132.4	84.70	84.70
Volatile	33.86		27.6	
Inorganic	98.49		57.1	
Chlorine	16.40		15.0	
Sulphur trioxide	32.50			
Ferrous oxide	13.71			
Free ammonia	2.461		4.51	
Albuminoid ammonia	0.759		0.547	
Free acid, in terms of sulphuric acid	18.745			

TABLE No. 3.

Columns 1, 2, and 3. Total number of pounds contained in twenty-four hours' flow of Mill brook at Cambridge street. Column 4. Total number of pounds in 1,000,000 gallons if the flow was 3,500,000 instead of 17,370,000 gallons, the total amount of solid matter remaining the same.

	No. 1, Jan. 14.		No. 2, Jan. 18.	
Total solids	52,057	52,057	51,586	51,586
Volatile	16,100		19,786	
Inorganic	35,957		31,800	
Suspended		11,457		14,814
Soluble	40,600	40,600	36,757	36,757
Volatile	9,570		10,230	
Inorganic	31,030		26,527	
Chlorine	4,970		4,617	
Sulphur trioxide	10,127		8,953	
Ferrous oxide	4,224		3,793	
Free ammonia	664		777	
Albuminoid ammonia	201		245	
Free acid, in terms of sulphuric acid	5,210		5,733	

	No. 3, mean of 1 and 2.		No. 4, amount in 1,000,000 gallons.	
Total solids	51,821	51,821	14,806	14,806
Volatile	17,943		5,127	
Inorganic	33,878		9,678	
Suspended		13,142		3,754
Soluble	38,679	38,679	11,051	11,051
Volatile	9,900		2,829	
Inorganic	28,779		8,222	
Chlorine	4,790		1,368	
Sulphur trioxide	9,540		2,726	
Ferrous oxide	4,008		1,145	
Free ammonia	720		206	
Albuminoid ammonia	223		63	
Free acid, in terms of sulphuric acid	5,477		1,565	

The above tables, on account of the very large flow of Mill brook at the present time, do not pretend to any very great degree of accuracy; but they show the general characteristics of Worcester sewage and give a basis from which deductions can be drawn.

They indicate, first, that Worcester sewage, taking the free ammonia as an index, contains about one-half as much organic matter in solution as the average English sewage, of which London sewage may be taken as a fair example.

That Worcester sewage contains a very large amount of inorganic salts.

That the amount of soluble sulphates and salts of iron in the sewage is very large.

That the sewage has a decidedly acid character, while sewage as a rule is of an alkaline nature.

These characteristics, which can easily be explained by noting the character of Worcester's chief industries, make it difficult to draw an analogy from any of the careful experiments made in England; and without practical experiments with our own sewage, my opinion as to the kind and amount of chemicals that are best to use can only be considered approximately correct.

In dealing with this question the two most important facts to be considered are, the acid character of the sewage, and the large amount of soluble sulphates and iron salts which it contains.

In all processes of chemical precipitation an alkaline sewage is necessary. To change the acid character of Worcester sewage to an alkaline character would be the first step, no matter what chemicals are afterwards to be used. This could, I think, be best accomplished by the addition of lime. The amount of quicklime necessary to add to 1,000,000 gallons of Worcester dry-weather sewage (taking Table 3, column 4, as the basis for calculation) would be about 900 pounds.

By the addition of this amount of lime the sewage would not only be made alkaline, but a part of the process of chemical precipitation would be accomplished.

Calcium sulphate, a heavy, fairly insoluble substance, would be formed, and a portion of the iron salts would tend to settle to the bottom of the liquid, carrying a part of the suspended organic matter.

The sewage would not be in a condition where a chemical precipitation process could be applied.

The various processes of chemical precipitation only differ from each other in the kind of chemicals used and the manner in which they are applied. For Worcester sewage I believe that the simplest of all processes, the addition of lime, would give an effluent that would be harmless when emptied into the Blackstone river, especially if, in very hot, dry weather, the effluent was run on to a small filtering bed. If not practicable to have a small filtering area, which I should consider desirable, the further purification in very hot weather, if found necessary, might be accomplished by the addition of a small amount of permanganate of potassium and sulphuric acid to the effluent.

I believe that the addition of lime alone would be sufficient, on account of the large amount of iron salts already in the sewage; the amount in 1,000,000 gallons equalling about 2,417 pounds of anhydrous iron sulphate, or 15 grains per gallon.

There is possibly a question whether the iron, being in the sewage before the addition of the lime, would bring about the same result as though added after the lime, as little differences like this often affect the results of a chemical process.

My opinion, though not based on experiments, is that the addition of sulphate of alumina, or the further addition of sulphate of iron, would be unnecessary when the sewage contained the amount of iron given above.

The exact amount of lime necessary to add is also a question that can only be answered after numerous experiments. I believe, however, that 15 grains of quicklime per gallon, or 2,150 pounds, added in the form of milk of lime, would be amply sufficient. If the quicklime before addition was dissolved in water, for which purpose sewage water could be used, probably only one-half of the above amount of quicklime would be necessary.

The precipitate thus produced, technically known as sludge, after being subjected to mechanical pressure by use of a Johnson filter press, would amount to about 6 tons for every million gallons of sewage, and might possibly be disposed of as a fertilizer, or could be used for the filling up of low land, or, if necessary, could be burnt in a Hoffman furnace, without causing any nuisance and probably without the use of any extra fuel.

It has already been stated that the sewage of Worcester is all discharged into Mill brook, one of the confluent tributaries which unite in the south part of the city to form the Blackstone. This brook has a known minimum flow of 2,000,000 gallons in 24 hours, and an estimated maximum flow of about 50,000,000 gallons in 24 hours. In designing sewage disposal works for Worcester, it appeared necessary to separate the sewage from the normal water flow of Mill brook. To effect this Mr. Allen proposes the construction of intercepting sewers, running as nearly parallel to Mill brook as possible, and so designed as to take all the dry-weather flow of the lateral sewers, only allowing the storm-water to overflow into the brook by storm overflows.

For this purpose intercepting sewers are proposed for each side of the brook, which are to extend through the entire length of the city and unite in the southern portion, at the junction of Cambridge and Millbury streets, from which point a single conduit 36 inches in diameter, which it is proposed to lay in the bottom of the invert of the large sewer in Millbury street, will extend to a point near the junction of Millbury and Vernon streets. From this point the outfall sewer is to diverge from the present sewer, and after crossing under the bed of the river, follow through Millbury street to Greenwood street, along Greenwood street a distance of about 1,000 feet, and from thence nearly parallel with the Providence and Worcester railroad to the location of the purification works, a short distance further south. This section is to be of brick, 42 inches in diameter, with a grade of 1 in 2,000. Its estimated capacity is 15,000,000 gallons in 24 hours. This capacity has in view a considerable growth of the city. Alternative plans for intercepting sewers are also suggested in the report, but inasmuch as they do not especially modify the method of purification which has been adopted, we need not separately refer to them here. The detail of the proposed scheme for chemical precipitation is suf-

ficiently exhibited for present purposes by the following estimates as condensed from the report:

ESTIMATE NO. 1. CHEMICAL PRECIPITATION WITH INTERCEPTING SEWERS.

East side intercepting sewer, from Lincoln square to Pond street, with changes in present system	$51,900 00
West-side intercepting sewer, from Lincoln square to Pond street, with changes in present system	62,300 00
Intercepting pipe, from Pond street to outfall sewer	41,250 00
Outfall sewer, from Mill brook to precipitation works	54,775 00
Building, Tanks, and Machinery	60,000 00
	$270,225 00
Add 15 per cent for Engineering and contingencies	40,533 75
	$310,758 75
Land and land damages	12,000 00
Total	$322,758 75

ESTIMATE NO. 2. INTERMITTENT FILTRATION WITH INTERCEPTING SEWERS.

East and West-side intercepting sewers, intercepting pipe from Pond street to outfall sewer, and outfall sewer from Mill brook to location of precipitation works as per previous estimate	$210,225 00
Outfall sewer extended from location of precipitation works to filtration area	45,135 00
Preparing 80 acres of land for filtration purposes	80,000 00
Subsiding tanks	10,000 00
	$345,360 00
Add 15 per cent. for Engineering and contingencies	51,804 00
	$397,164 00
Land and land damages	42,000 00
Total	$435,164 00

In regard to the possibility of combining, at some time in the future, chemical treatment with intermittent filtration, it is stated that the additional expense, above the cost of the precipitation scheme alone, would be either $197,405.25 or $214,800.00, the difference depending upon which of two available filtration areas might be selected.

In regard to the cost of operation, it is stated that the estimates of annual expense are based upon a cost of 45 cents per person per year. Assuming that the sewage of 50,000 people, amounting to 3,000,000 gallons per day, now enters the sewers, the annual cost upon this basis is found to be $22,500 per year. The annual cost of operating intermittent filtration for 3,000,000 gallons per day, constantly treated, was estimated at $11,200 per year. But these estimates of cost do not, in either case, include either interest on the cost of the plant or the

annual sum to be set aside for renewals and depreciation; they merely include the actual running expense per year.

In concluding his elaborate report, Mr. Allen states that his reasons

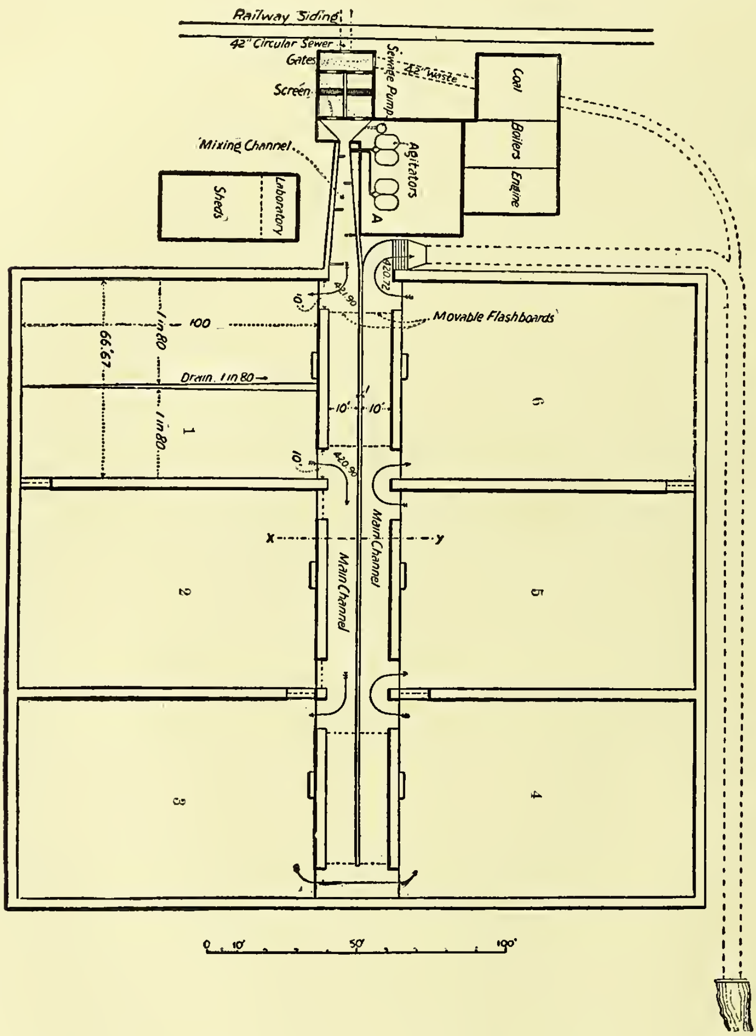


FIG. 60.—PLAN OF SEWAGE DISPOSAL WORKS, WORCESTER, MASSACHUSETTS.

for preferring the method of purification by chemical treatment at Worcester are as follows:

1. That the effluent obtained will without doubt conform to the requirements of the law.
2. That the cost of establishing a plant will be less than by either irrigation or downward intermittent filtration.
3. That chemical precipitation will not be affected by climatic conditions.
4. There will be no loss of water, and consequently no water damages to pay.

5. If this method of disposal is adopted by the city of Worcester, it will be in a position to take advantage, without material change in plant, of improvements that will undoubtedly be made in the methods of sewage disposal.

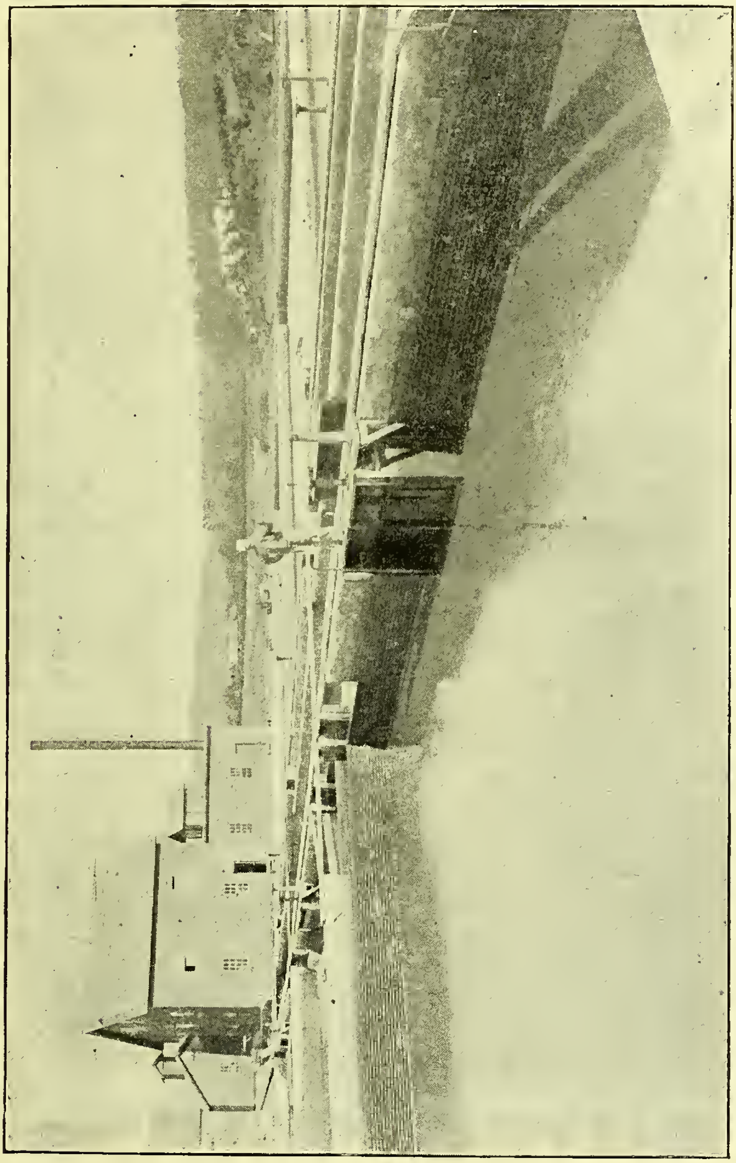


Fig. 61.—General View of Worcester Disposal Works.

6. That precipitation will be a valuable auxiliary to irrigation or intermittent filtration, if it should ever be thought desirable to add either of these methods of disposal to the system.

Following Mr. Allen's report of 1887, from which we have quoted at length, on May 14, 1888, the City Council adopted an order for the construction of the outfall sewer from the main channel of Mill brook to the proposed location of the precipitation works. This section of the sewer was built at an actual cost of about $69,000.

FIG. 62.—VIEW OF CENTRAL CHANNEL, WORCESTER PRECIPITATING TANKS.

On July 8, 1889, the City Council ordered the construction of the precipitation works, and work began as soon thereafter as the detailed plans could be sufficiently matured. The general plan of the precipitating works is shown by Fig. 60; two views by Figs. 61 and 62; and the details are illustrated by Plate IV., which shows, Fig. 1, a section of the outfall sewers leading to the purification works, where it passes under the river; Fig. 3, a section of the central channel and the pipe arch; Fig. 4, the effluent pipe and sludge drains in place. The main sludge drain is connected with the sludge well located in the basement of the machinery building at point A, Fig. 60. Fig. 5 is a self-explanatory section of the side and middle walls. The overflow steps and effluent drain are shown by Figs. 6, 7, and 8, also on Plate IV.

In regard to the method of treatment which has been finally adopted, Mr. Allen in his report for the year ending November 30, 1890, says:

The treatment which we have finally adopted is the "continuous process." The sewage, after leaving the outfall sewer, enters the receiving chamber in the gate or

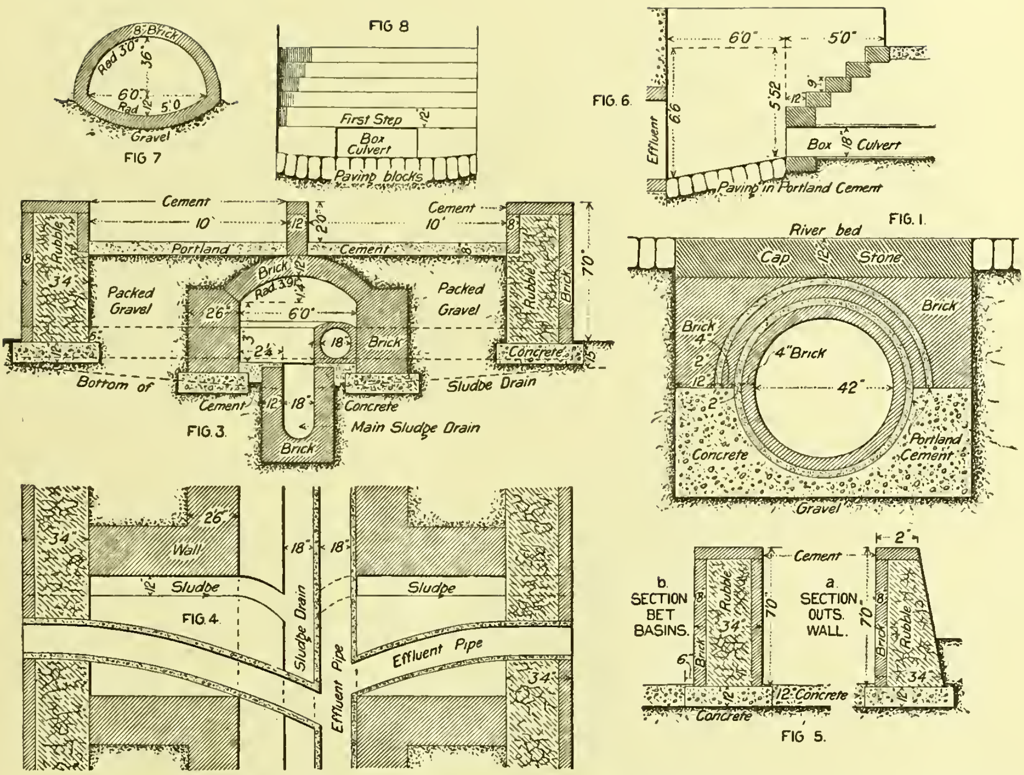


PLATE IV. DETAILS OF WORCESTER PRECIPITATION TANKS.

screen house. It then passes through the screens, where all matter that would tend to clog the sludge-pump are screened out, such as paper and sticks of wood. It then passes through the outlet chamber into the mixing channel. The chemicals are introduced at the upper end of this channel, being discharged through pipes connected with the vats inside the building. After the introduction of the chemicals the sewage flows through the mixing channel, the chemicals being thoroughly mixed with it by the agitation produced by the baffle-plates. From this channel the sewage passes through the first weir into tank No. 1. Here there is a fall of one foot, which tends to more thoroughly mix together the sewage and chemicals. It then passes very slowly through tank 1, out of this tank through the second weir into the main channel, then through the third weir into tank 2, through tank 2 into tank 3, and thence through tanks 4, 5, and 6, until it is discharged finally through the last weir and over the overflow steps into the effluent drain, and from thence into the river; it takes about six hours for it to pass through all the tanks. The position of the weirs and the general arrangement of the tanks is shown by Fig. 60.

When it becomes necessary to clean a tank, the flash-boards are placed in the weirs connected with this tank, and the sewage is passed around into the next tank through the main channel. Tank No. 2, in Fig. 60, is represented as being cut out.

The sewage in the tank to be cleaned is then allowed to rest from three to six hours, so that thorough precipitation will take place before the water is drawn off.

In front of each effluent pipe, and projecting into the tank, is a flume of wood. This flume is so constructed that the water can be drawn from the surface by means of flash-boards 6 inches deep. When the time has arrived for drawing the water, the first flash-board is removed and the gate at the mouth of the effluent pipe is opened. The water flows over the top of the second flash-board, through the gate and effluent pipe into the effluent drain, and then into the river. This method is repeated until all the boards have been removed, and the water drawn down to the

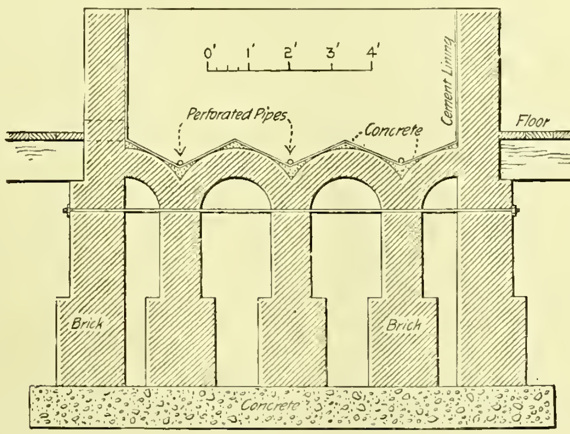


Fig. 63.—New Chemical Agitator, Worcester, Massachusetts.

level of the sludge. The gate at the mouth of the sludge-drain is then opened, and the sludge flows through the sludge-drains to the sludge-well under the building. It is pumped from this well into a pipe carrier, and flows by gravity to the sludge-beds, located on land owned by the city, situated on the easterly side of the Providence & Worcester Railroad, and entirely removed from the works. This land (about 16.5 acres) was selected for this purpose owing to its very favorable location. It is situated between the railroad and the river, is entirely isolated, there being no way to reach it except through land owned by the city. The liability of complaint being made by reason of its near proximity to buildings is thus reduced to the

minimum. A little over one-half of the area is low, swampy land; the remainder is covered with knolls of gravel.

At present 11 sludge-beds are in use, all being located on the low land. They are formed by removing the turf from the surface and constructing dikes with the soil removed. The beds are rectangular in shape, and are about 100 feet square. One day's sludge is pumped into each bed. It is then allowed to rest for 11 days, the second bed receiving the sludge the next day, and so on through the series. This is done to avoid any possible chance of a nuisance arising from any one bed being overcharged. Occasionally a layer of gravel is spread over the accumulated sludge. In this way it is intended to grade the surface of the entire area, after which it is intended to erect a destructor upon the land and burn the sludge—which, from experiments that have been made, I am convinced can be easily done. These beds have been in almost constant use since the works were put in operation, and there has never been the least trace of bad odor arising from them even during the hot summer months. This is, without doubt, due not only to the care that has been used in not allowing them to be overcharged, but also to the character of the sewage, and therefore to the character of the sludge, it being heavily charged with iron salts and lime. Everything that would tend to create a nuisance seems to be entirely killed out.

The precipitation takes place principally in the first three tanks. The sludge has to be removed from tanks Nos. 1 and 2 about once in 36 hours in warm weather, but during cold weather we have been able to go four days without cleaning, without perceptibly affecting the character of the effluent. Tank No. 3 is cleaned every two or three days in warm weather, and once in 7 or 8 days in cold weather. Tanks 4, 5, and 6 accumulate very little sludge; but they are cleaned as often as is necessary—about once a week in the hottest weather, and once in three weeks during the colder period. In the first two tanks during warm weather, or when the sludge is removed once in 36 hours, the accumulation is about 10 inches deep over the entire bottom surface. No. 3, when cleaned once in three days, has a depth of sludge of about 8 inches. Nos. 4, 5, and 6, when cleaned once a week, have an accumulation of about 6 inches. The sludge is about 95 per cent. water, and after it has been spread upon the sludge-beds for about 9 days this almost entirely disappears. The precipitant principally used at the works is Vermont lime. This has proved to be much better for our use than either Eastern or Western lime. It costs, delivered at the works, about $7.00 per ton. The sulphate of alumina, which is used in limited quantities, costs about $25.00 per ton delivered.

The sewage is extremely acid, owing to the fact that large quantities of sulphuric and muriatic acids are discharged into the sewers from iron manufacturing establishments. This acid does not appear at the works in uniform quantities, but is extremely intermittent. It generally makes its appearance once in about 6 hours, although there is always acid present in the sewage. The heavy flow of acid sewage generally lasts about one and one-half hours.

In order to get perfect precipitation and a good effluent, we have found that it is necessary to neutralize this acid, or, in other words, to make the sewage alkaline. This is done by introducing a sufficient quantity of lime to accomplish the object. It is therefore necessary to test the sewage at very frequent intervals during the 24 hours. Samples of the sewage are taken in glass beakers after the chemicals are introduced, and the test is made in the laboratory. As a test for alkalinity, phenolphthalein is used. A very small quantity is dropped into the beaker of sewage, and if the liquid turns red the sewage has been made alkaline by the lime; if the color remains unchanged more lime must be introduced.

The sulphate of alumina is used with the lime on occasions when there is not sufficient iron salts in the sewage to act with the lime in producing a good effluent, generally Sundays and Mondays. The quantity of lime used varies with the varying character of the sewage. We have found by experience that there is no fixed rule that can be followed. The number of grains per gallon varies from 1 to 200 of lime, and from 1 to 40 of alumina. The larger amounts are for short intervals of time, so that the average for 24 hours rarely exceeds 8 grains of lime and 4 of alumina per gallon.

When operations were first begun the tanks were used intermittently, and a fixed

amount of lime per gallon was used; that is, 15 grains, say, of lime per gallon was used without regard to the character of the sewage, as is the practice in many of the European works. It was soon found out that while at times the effluent would be very fine, at other times it would be very poor, and we soon found that, in order to obtain a uniformly good effluent, the quantities of lime or alumina had to be increased or diminished as the character of the sewage varied; so the series of tests previously spoken of were resorted to, and have been constantly adhered to since, with the result of obtaining an effluent of remarkably uniform character.

After we were satisfied that we had discovered the correct principle of applying and mixing the chemicals, the tanks were used continuously—*i.e.*, the sewage was allowed to run through the entire series, as at present—and this plan has been followed ever since.

At first, there were days at a time when as high as 4 tons of lime was used, and very much larger quantities of alumina than at present. Experiments without number were made to see if this excessive use of chemicals could not be reduced, and finally the following plan, which has been extremely satisfactory, was hit upon.

The arrival of the acid sewage at the works is anticipated, and preparations are made so that when it arrives it is thoroughly treated with lime, making it alkaline. As this flow generally lasts an hour and a half at a time, tanks 1 and 2 become heavily charged with it. After this extremely acid sewage has passed into the tanks, the machinery is stopped, and no more chemicals are added until the arrival of the next dose of acid in large quantities—generally from four to five hours.

During this interval of time, the sewage that passes by the works and into the tanks is so thoroughly treated by the iron salts and lime present in the extremely acid sewage that has just preceded it, that the effluent is as good, if not better, than it would be if chemicals were applied as it passed the works. In other words, there is an excess of chemical matter in the acid sewage after the lime is added, which is utilized as a precipitant by passing crude sewage through the tanks heavily charged with it. Experience has demonstrated that crude sewage passed through tanks 1 and 2, previously filled with the acid sewage, will become mixed with it, and that this can be relied upon to do its work thoroughly for intervals of from 4 to 5 hours. This has resulted in the saving of large quantities of lime, the amount now used per day being about one-half the amount used for some time after the works were put in operation.

All the lime and alumina used is weighed in the chemical room before it is turned into the vats. In this way the number of grains per gallon is determined.

I have already described the manner in which the sewage is tested, the object being to have it alkaline when it enters the tanks. If it is necessary to increase or diminish the quantity of chemicals used, the person making the tests gives the order through a speaking tube connecting the laboratory with the chemical room. All orders are given in grains per gallon. For instance, if it is desired to use 10 grains of lime per gallon, 12 lbs. of lime is poured into the vats once in 4 minutes. If it is necessary to increase to 20 grains per gallon, 23.75 lbs. is used every 4 minutes; thirty grains calls for 26.75 lbs. every 3 minutes; fifty grains calls for 44.75 lbs. every 3 minutes; 100 grains, 89 lbs. every 3 minutes; 150 grains, 89 lbs. every 2 minutes; 200 grains, 119 lbs. every two minutes; 300 grains, 89 lbs. once a minute. The above is on a basis of 3,000,000 gallons in 24 hours. Tables have been prepared, and are kept in the chemical room in a conspicuous place, so that the operative there can tell at a glance the number of pounds of lime or alumina he is to put into the vats in response to the order from the laboratory.

It is not my purpose in this report to give the result of analyses made of the effluent. We have not sufficient data at hand to give a correct idea of its true character. The analyses should extend over a long period of time before a result that can be relied upon can be obtained. It is sufficient to say that we know all the suspended matter is removed, that the organic matter carried in solution is very largely reduced, and that the free and albuminoid ammonias are also largely reduced.

As a practical illustration of what is accomplished, samples of the sewage and of the effluent taken at the same time have been saved. Sewage five months old is the color of ink, and the odor from it is so foul that it is sickening; while the

effluent of the same age is clear, colorless, and entirely without odor. I am perfectly satisfied that no decomposition takes place in the effluent, and that so far as the Blackstone river is concerned, it is as unobjectionable as spring water would be. I do not claim that drinking water is manufactured at the disposal works: what I believe is, that the method of treatment is such that when the whole sewage of the city is dealt with at the works, the Blackstone river will be entirely relieved of any further pollution by the city of Worcester.

As to the cost of treatment, Mr. Allen states that it is constantly being reduced, and at the time of making his report is well within his estimate of 1887, namely $22,500 for 3,000,000 gallons per day, constantly treated.

On June 17, 1892, Mr. Baker visited the works and obtained the additional and later information given below.

For some time after the plant was put in operation 3,000,000 gallons of sewage were treated daily. This amount was afterward increased, and on June 19, 1891, the daily treatment of 6,000,000 gallons was begun, it being considered better to partially treat this amount than to treat a smaller amount thoroughly. In 1892 the construction of 10 new tanks was begun, making 16 in all. The information secured regarding the more recent operation of the plant and the extensions is as follows:*

Originally the lime was ground at the works, but now it is slaked in a vat, a ton at a time. In this way about 23 per cent. of lime and 30 horse-power are saved, which is partially offset by the fact that the lime must be slaked by hand. Either sewage or water may be used for slaking.

The agitators formerly used to mix the chemicals are still used, but this is because there is no other means of getting the lime through the pipes to the sewage below.

During the year ending Nov. 30, 1891, there were treated 1,399,000,000 gallons of sewage, or about 3,830,000 gallons daily, from which 22,042,000 gallons of sludge was precipitated, the sludge having been pumped to sludge-pits. The solids in the sludge aggregated 1,230 tons, or about 3⅓ tons a day, all of which was diverted from the river.

The amount of lime used during the year was 757.8 tons, and of alumina 64.65 tons. These chemicals were used in varying quantities, and often the alumina was not used at all; still, giving the averages for what they are worth, we find that for the whole year the average amount of lime used per gallon was 7.6 grains, and of alumina 0.65 grains.

The disposal of the sludge, the solid part of which amounted in 1891 to 3⅓ tons per day, has been a serious problem from the start. At first the sludge was put in heaps and covered up, but this did not give satisfaction. Three different sludge-furnaces were tried, but the

* Eng. News, vol. xxviii. (July 28, 1892), pp. 77–8.

labor involved was too great, although the sludge formed its own fuel after once kindled. In one of these furnaces sludge containing 50 per cent. water burned quite rapidly, while some containing 72 per cent. of water burned at the rate of 2.225 tons in nine hours, unaided by other fuel. In the spring of 1892, the sludge which had accumulated since September, 1891, was carted away at the expense of the city and put on to farm land.

As late as the spring of 1892 there were only eleven sludge-beds, covering an area of about three acres. These had been overworked until they were almost useless. When the sludge on the beds did not exceed a few inches in depth it was found that it dried quite rapidly. An area of 5.7 acres was therefore added to the sludge-beds. The first beds were not underdrained, but the later ones have been. The sludge passes to the beds through wooden troughs.

The new tanks will have the same capacity each as the old ones, but will be of a different shape, their dimensions being $40 \times 166\frac{2}{3}$ feet, 5 feet deep from the top of the weir. Sewage will discharge about 18 inches deep over the weir. The old tanks were $66\frac{2}{3} \times 100$ feet, 5 feet deep. There will be ten of these tanks, increasing the capacity of the plant to 15,000,000 gallons per day and providing for the treatment of the entire dry-weather flow of sewage, which in April, 1893, was reported as varying from 11,000,000 to 15,000,000 gallons per day.

On June 15, 1893, Mr. Baker visited the works for the second time, and found some interesting features being introduced in connection with the extension of the tank system. A new form of lime agitator is to be used, as shown in cross-section in Fig. 63 (page 435). In the new agitators the lime will be mixed and kept from settling by means of compressed air. Two masonry tanks, each 8 by 16 feet, will be used for the lime. The bottoms of the tanks will have an undulating surface, as shown in Fig. 63, and in each of three longitudinal depressions there will be a $1\frac{1}{2}$-in. wrought iron pipe, perforated every 28 ins. with $\frac{1}{4}$-in. holes, the holes in each pipe alternating with those in the other.

The air will be furnished by a Rand air compressor, with 12×16-in. double cylinders, there being ample boiler power available to drive it. The air will keep the lime continually agitated, and it is proposed to slake it in lots of $2\frac{1}{2}$ tons.

As practised in 1892 and the first half of 1893, the lime was slaked and kept stirred by means of a hose, two men sometimes being required for the work.

An 8-in. pipe will connect with the new lime tanks and convey the lime to the inlet channel at a point nearly 100 feet above the old lime inlet, which was just below the screens, at the throat of the salmonway or baffle-plates.

The practice of putting the sludge upon sludge-beds will be con-

tinued, but the sludge from the new settling tanks will pass to an open channel and thence to a Shone ejector, the air for which will be compressed by power from a 21-in. Holyoke turbine driven by the effluent from the top of the tanks, which will give a head of about 7 feet on the turbine. The ejector will have a capacity of 35,000 gallons per hour.

In 1892 the city hauled the sludge to the land of some farmers, and gave it to them in order to introduce it. In 1893 the farmers have hauled the sludge themselves, but have not paid the city for it. The sludge has been found to give good results with many different crops, and especially with corn, potatoes, and rye.*

* The chief sources of information in regard to the sewage disposal works at Worcester as actually carried out (in addition to the references already given) are:

(1) Rept. of the City Eng. to the City Coun., in re. Disposal of the Sewage, etc., 1887.
(2) An. Repts. of the Com. of Sewers, the Supt. of Sewers, and the City Eng., etc., for yr. end. Nov. 30, 1890.
Also see Eng. News, vol. xxiv., p. 432 (Nov. 15, 1890).

CHAPTER XXVIII.

DISCHARGE INTO TIDE-WATER AND PROPOSED CHEMICAL PRECIPITATION AT PROVIDENCE, RHODE ISLAND.

THE city of Providence, Rhode Island, situated at the head of Narragansett Bay, is the second city in New England. The population in 1850 was 41,513 ; 1860, 50,666 ; 1870, 68,904 ; 1880, 104,857 ; 1890, 132,146.

The city is intersected by the Woonasquatucket and Mashassuck rivers, which, uniting to form the Providence river, divide it naturally into three sections. The Seekonk river is on the eastern boundary. The eastern section is high, its extreme elevation being over 200 feet, and falling away abruptly to the west toward the Mashassuck river, and also inclining gradually toward the south to the harbor. On its easterly border are the cliffs of the Seekonk river, from 20 to 50 feet in height. A large portion of the southwestern section is from 60 to 70 feet above tide-water. The northwestern section generally rises in a northwesterly direction, with a large portion above an elevation of 90 feet, while much of it ranges from 150 to 190 feet, with the highest point in the neighborhood of 200 feet. The surface of this portion is diversified by hills and dales. The topographical features of nearly the whole city are, therefore, generally such as to give unusual advantages in respect to sewerage and drainage.

Previous to 1871 no systematic system of sewerage existed at Providence. In that year a comprehensive plan was prepared, and the construction of sewers begun under the direction of the Board of Water Commissioners, with J. Herbert Shedd, M. Am. Soc. C.E., as chief engineer. At that time there existed about 8.5 miles of old stone sewers and drains, which were used to a considerable extent for house drainage. None of the original sewers were incorporated into the present system, although some are still used as surface-water conduits only.

The original sewers, as well as those designed in 1871, discharge into the intersecting rivers and the harbor at the most convenient points. The fact was fully recognized in the formal design, that in the end the pollution of the streams and the harbor would become such as to necessitate some other arrangement; and accordingly Mr. Shedd's plans included the ultimate construction of a series of intercepting

sewers, by which the entire flow of sewage would be conveyed to Field's Point, at the southern extremity of the harbor, and there discharged with the ebb of the tide into deep water. The mean range of the tide at Providence is about 4.7 feet.

In 1874 Mr. Shedd, in response to a resolution of the Board of Aldermen of November 26, 1873, asking for information in regard to the general plans on which the sewers had been constructed to that date, submitted an elaborate report, in which is discussed nearly every question of interest in connection with the design of the Providence sewerage system. The report is of special interest and value, by reason of containing the first thorough analysis of the relation of maximum rainfall to size of sewers to be found in American sanitary literature. In this particular, Mr. Shedd's report of 1874 is an engineering classic, and has been the model upon which nearly all the American sewerage reports since made have been based.

Considerable opposition, however, was developed among the citizens of Providence to the plans for sewerage which Mr. Shedd had prepared, and in order to get an authoritative expression of opinion from a disinterested source, the Mayor of Providence requested the Board of Directors of the American Society of Civil Engineers to designate three members of that Society to make an examination of the sewerage system adopted by the advice of Mr. Shedd, and report as to the sufficiency of size, kind of material, division of districts, etc.; and also to recommend any changes which they might deem requisite. Gen. Geo. S. Greene, Col. Julius W. Adams, and E. S. Chesbrough were designated as such Commission. Their report approving the system designed by Mr. Shedd was presented under date of August 7, 1876.

In regard to the final delivery of all the sewage at Field's point, Messrs. Greene, Adams, and Chesbrough say:

> The project of ultimately carrying all the sewage into the deep-water current at Field's point is judicious and proper, and should be constantly kept in view in all constructions of marginal or outlet sewers, and in plans for right-of-way for sewers leading toward that point. It is probable that, to preserve the sanitary condition of the waters of the Providence and Seekonk rivers, it will be necessary to discharge the sewage ordinarily at ebb-tide, and to have a reservoir near the outlet to enable this to be done. The property of the city on Field's point contains a proper site for such works.
>
> Should the sewage ever be of sufficient value to justify the use of it for irrigation, this point will be the position from which it can be most easily carried to the dry plains on either side of the Pawtuxet river, by pumping it to a sufficient height for distribution.

The considerable increase in population, together with a corresponding extension of the manufacturing industries of Providence, had led to such relatively rapid increase in the pollution of the Providence river and its tributaries, as to force upon the city authorities the ques-

tion of some disposal of the sewage other than by allowing it to pass directly into the several streams. In September, 1882, the City Council directed Samuel M. Gray, M. Am. Soc. C.E., who was then city engineer, to report plans of main intercepting sewers, and of any other work necessary for collecting, conducting, and disposing of the sewage of the city, in accordance with the best approved methods, at such a point and in such a manner as would be the least injurious to the public health, together with the estimated cost thereof.

Subsequently, on February 23, 1884, the City Council directed Mr. Gray and his assistant, Chas. H. Swan, M. Am. Soc. C.E., to proceed to Europe to investigate the various plans in practical operation for the disposal and utilization of sewage, together with all matters relating thereto, and to report the result of such investigations, with such recommendations with reference to the sewage of the city as might be deemed expedient.

In accordance with these instructions, Messrs. Gray and Swan proceeded to Europe and inspected the sewerage systems and methods of sewage disposal at the following places:

The pail system at Birmingham and Manchester.

The Liernur pneumatic system at Amsterdam.

The Berlier system at Paris.

The Shone system at Wrexham.

The combined system at London, Berlin, Paris, and Frankfort-on-the Main.

The separate system at Oxford, and also at Paris, where it was in experimental operation to a limited extent.

Irrigation farms at Bedford, Berlin, Breslau, Croydon, Dantzic, Doncaster, Edinburgh, Leamington, Milan, Oxford, Paris, Warwick, Wimbledon, and Wrexham.

Precipitation works at Aylesbury, Birmingham, Bradford, Burnley, Coventry, Hertford, Leeds, and Leyton. Precipitation works in process of construction were also inspected at Frankfort-on-the-Main.

As the result of his investigations, Mr. Gray recommended:

(1) That a system of intercepting sewers be completed.

(2) That the system of intercepting sewers be so designed as to convey the sewage of the city to Field's point.

(3) That the sewage be treated at Field's point by chemicals in such manner as to precipitate the matters in suspension and to clarify the sewage.

(4) That the clarified effluent be emptied into deep water at Field's point.

In regard to precipitation, Mr. Gray says:

My reason for recommending precipitation is that I am confident that the sewage can be so clarified that the effluent will be entirely harmless when emptied into the river at Field's point, and the purification can be accomplished at less expense than by irrigation. Although sewage is more fully purified by irrigation than by pre-

cipitation, I have not felt justified in recommending its adoption, for, from careful and extended surveys, I am convinced that the large amount of suitable land required for irrigation cannot be obtained at any reasonable cost within reasonable distance of the city.

. . . It is proposed to erect pumping works. The sewage from a part of the eighth ward and from most of the ninth will not require pumping. The sewage from the remainder of the city will be lifted about twenty-eight feet into a conduit, through which this sewage, together with that from the eighth and ninth wards, already referred to, will flow to the precipitation works. . . . .

At this point . . . it is proposed to construct tanks and erect suitable buildings and works for the mixing of chemicals with the sewage, and for the handling of the sludge, etc. The sewage, after receiving the mixture of chemicals, will flow into precipitation tanks, where it will remain for a short time to cause the deposit of sludge; the clarified effluent will flow off into deep water at the point as shown on the plan.

The sludge left in the bottom of the tanks will then pass into receivers, from which it will be forced by compressed air into filter presses. . . .

. . . By these presses the sludge is easily compressed into a portable form. That this sludge possesses some value as a fertilizer there is no doubt; it remains to be proved whether there will be any sale for it in this vicinity. Therefore, for the purposes of this report, I assume that there will be no immediate income from its sale as a fertilizer.

Before deciding the question of discharge of crude sewage at Field's point *versus* precipitation before discharge, extensive experiments were made with floats, in order to ascertain what probable action the tide and currents would have on the sewage. In regard to the results, Mr. Gray says:

From a careful study of these experiments, and from a long and close observation of the causes of the present pollution of the cove, the Providence river, and its tributaries, I am of the opinion that if the crude sewage of the city be emptied into the river at Field's point it will inevitably cause a nuisance, to the injury not only of the dwellers within the city, but to the occupants of many of the shore resorts and residences bordering on the Providence river and Narragansett bay, and will seriously damage, if not destroy, many of the valuable oyster beds which now line the shores. . . . .

. . . A very important factor in the pollution of the cove, as well as the Providence river and its tributaries, is the liquid wastes of manufactories emptied into the rivers. There are, as near as I can estimate from the best obtainable data, upward of 2,735,000 gallons of filthy liquid wastes emptied daily (Sundays excepted) into the Mashassuck and West rivers, and upwards of 2,088,000 gallons into the Woonasquatucket river, making a total of 4,823,000 gallons of filthy liquids, aside from town sewage, emptied into the several rivers during twelve or fourteen hours out of the twenty-four. I wish to call your attention emphatically to the fact that however thoroughly the town sewage may be kept from the rivers, if these foul liquids from manufactories are allowed to enter the streams, as at present, the cove, together with the Providence river and its tributaries, will continue to present about the same filthy appearance that they do to-day. It is only by keeping all sewage and filthy liquids out of these waters, or by clarifying them before they are permitted to enter, and by thoroughly clearing the river beds from all deposits of filth, that we may look for improvement in the condition of the Providence river and its tributaries. I am convinced from observations abroad that in some cases the quantity of liquid wastes now emptied into the rivers from manufactories might be materially reduced, and that the remainder could be so clarified by the proprietors as to prevent polluting the river, and possibly result in some instances in a source of income to them.

In designing the sizes of the intercepting sewers, I have thought best to make

provisions for receiving the liquid wastes of these manufactories. It is an important question for your consideration on what conditions it may be advisable to admit these liquid wastes into the sewers.

The estimated daily dry-weather flow of town sewage in Providence at the present time (1884) is about 3,000,000 gallons. This is based on careful and extensive gaugings, made at different times, of the amount of sewage flowing in the several sewers. . . . .

. . . It will be seen by table of gaugings that the sewers laid in wet localities furnish a much greater quantity of sewage per inhabitant connected, than do the sewers laid in drier parts of the city. This larger quantity of sewage is due in most localities to spring or ground water, which finds its way into the sewer. The great value to the general health of the community of thus draining the ground is too apparent to need comment.

In designing the intercepting sewers, liberal provision has been made for a population of 300,000 inhabitants within the present city limits, together with small districts lying outside the present limits, whose only outlet will be through the city.

The Providence sewers are entirely constructed on the combined system.

In his original design of 1871, Mr. Shedd based the sizes of sewers upon an estimated maximum amount of $30\frac{1}{4}$ cubic feet of rainfall per minute per acre reaching them. The reasons for adopting this figure are presented in detail in Mr. Shedd's report of 1874.

Mr. Gray states in his report of 1884 that the intercepting sewers (excepting the main sewers of the ninth ward) are designed to carry $\frac{1}{100}$ inch of water per hour from the area drained, together with the manufacturing wastes and 60 gallons of sewage per inhabitant, including ground-water. The manufacturing waste is estimated as flowing off in ten hours, while one-half of the domestic sewage is estimated to flow off in seven hours. The balance of the flow from the rainfall, when in excess of the foregoing allowances, is to be disposed of through storm overflows, which will discharge the excess directly into the streams.

In the ninth ward the flatness of the territory, the long valleys, and the absence of streams to receive the overflow, render it desirable to provide for more surface-water than in other parts of the city, where overflows can be easily and safely made. In this district, therefore, provision was made for two inches of rainfall per hour, in addition to the sewage.

An overflow is to be provided for the ninth-ward sewer into the cove, near the proposed pumping station.

The estimated cost of the whole work recommended by Mr. Gray was $3,699,504.

In regard to the various suggestions for disposing of the sewage of Providence by irrigation and otherwise, Mr. Gray says:

Experience indicates that the amount of land required for the disposal of sewage by irrigation is about one acre to one hundred inhabitants. The population provided for in the proposed system of intercepting sewers is 300,000. The amount of

land necessary to properly dispose of the sewage of that population would be about 3,000.

It has been suggested to take the sewage to Seekonk plains for irrigation. The great expense of conveying the sewage across the Seekonk river and to this land, together with the fact that the available area is less than one thousand acres, forbids a consideration of this scheme.

It has also been suggested that the sewage be taken to Warwick plains and there used for irrigation. From extensive surveys of this territory, I am satisfied that there is not a sufficient quantity of suitable land in that locality for the future needs of the city. The estimated cost for construction in accordance with this suggested scheme, including only sufficient quantity of land for the present needs, is $1,146,-000 more than for the plan of precipitation herein recommended. The annual cost of pumping the sewage to Warwick plains would be double the cost of the pumping required in the plan recommended. Considering the additional cost, and in view of the fact that there is not a sufficient quantity of land at Warwick plains for future needs, I deem it unnecessary to further consider this scheme.

By combining precipitation with irrigation a much smaller area of land is requisite, and should it hereafter be deemed advisable to adopt some system of irrigation, the proposed precipitation works will form a most useful auxiliary.

Another suggestion has been made, which is to take the sewage down the river to Conimicut point, and there, in its crude state, discharge it into the bay. I estimate that the carrying out of this scheme would cost $1,194,000 more than the plan I have recommended. The annual cost of pumping to Conimicut point would be nearly double the cost of pumping in accordance with the plan recommended. Moreover, the experiments made at this point with floats show that there are strong reasons for fearing that crude sewage emptied into the bay at this point would create a nuisance in the not distant future.

Considerable opposition having developed among the citizens of Providence to the plan of intercepting sewers and sewage disposal, as suggested by Mr. Gray in his report, the City Council again requested the American Society of Civil Engineers to appoint three members of the society, skilled in sanitary engineering, to visit Providence and examine Mr. Gray's plan for a sewerage system and for sewage disposal works, and to report to the City Council their opinion as to whether the said plans were the best and most economical which could be adopted for the collection and disposal of the sewage of the city; and, if not, to recommend any changes which they might deem advisable.

In accordance with this resolution, the President of the American Society of Civil Engineers appointed Messrs. Joseph P. Davis, Rudolph Hering and Robt. Moore, Members of the Society, as a Commission for this purpose. These gentlemen visited Providence, examined Mr. Gray's plans, profiles, estimates, and computations, and submitted their report under date of December 21, 1886.

After defining the various practicable methods of sewage disposal, the Commissioners say:

We may now proceed to a consideration of the several plans which have been proposed for dealing with the sewage of the city of Providence. These are:

1. Disposal at Seekonk plains;
2. Crude disposal at Field's point;
3. Disposal at Warwick plains;
4. Precipitation at Field's point;

each of which we will consider in the order named.

I. DISPOSAL AT SEEKONK PLAINS.

In considering the scheme for disposing of the sewage at Seekonk plains, for which Mr. Gray, in his report of February 2, 1886, has submitted an estimate, the fact at once appears that if broad irrigation be adopted, the amount of land available for this purpose (being less than 1,200 acres) is barely sufficient for present requirements, and leaves no margin whatever for the future needs of the city. Intermittent filtration, for which the land is fairly suitable, is the only method of disposal which should be seriously considered at this point. We find, however, that much cheaper land, of equally good or better quality for this purpose, exists at Warwick plains, a point more remote from the centre of population, and where, because of this remoteness from habitation, carelessness in the management of the process will cause much less annoyance than at Seekonk plains. These and other considerations of minor importance make it evident that the advantages for disposal of the sewage on the land are much greater at Warwick plains than at Seekonk plains; and we think it is, therefore, useless to enter into any detailed discussion of plans for the latter place.

II. CRUDE DISPOSAL AT FIELD'S POINT.

The discharge of the sewage in its crude state at Field's point, although involving works of somewhat greater first cost than are required for precipitation, is yet, on account of its smaller current expenses, by far the cheapest of all the modes which have been proposed for disposing of the sewage of the city. We understand, however, that the sentiment of the citizens of Providence is much opposed to this method of disposal. Nor is this surprising. The shores in this vicinity are used for summer residences and as pleasure resorts; bathing beaches are near at hand, and during the summer and fall months these waters are much frequented by excursion parties, attracted by the cool breezes of the bay and the beauty of its shores. Extensive oyster beds exist in this vicinity, and the fishing interests are said to be of some importance. The float experiments made by Mr. Gray show that the strong and well-defined outward tidal current, which is found opposite Field's point shortly after the ebb tide sets in, begins below this point to diminish in force and become diffused. The direction of the surface currents is greatly influenced by the wind, but, as a rule, matter discharged at the Point during the hour and a half after high tide, would meet the incoming tide before reaching Gaspee point, and would be carried backward a considerable distance toward its place of starting, unless sooner grounded on one of the shores. With a westerly wind, the tendency is to strand on the east shore, and probably the bathing beaches on that shore, between Squantum and Sabine's point, and even below, would be much injured.

Considering all the interests at stake in preserving the bay and its shores from even the apprehension of nuisance—interests of a kind which relate to the health and pleasure of the people, and cannot, therefore, be measured in money values—we are of the opinion that the plan of crude disposal at Field's point, by which these interests might be jeopardized, is inadmissible.

III. DISPOSAL AT WARWICK PLAINS.

At Warwick plains are found about 2,200 acres of land available for irrigation. The soil is of good character for this purpose, and the situation is in many respects favorable. But looking to the future, when the city of Providence shall have a population of 300,000, this is not sufficient land to dispose of the sewage in a satisfactory manner by broad irrigation. On this account, and also because we find disposal by intermittent filtration to be the cheaper and, all things considered, the better method, we have made an estimate of the cost of a scheme for this method of disposal, and shall use it, rather than the estimate for broad irrigation given in

Mr. Gray's report, for purposes of comparison with the scheme of precipitation at Field's point.

In making this estimate, we have assumed that 1,000 acres of land will be purchased at once, not only to allow for the future needs of the city, when the land may be much more difficult to acquire, but also to afford in the first instance greater latitute in the management of the farm. Filter beds are well adapted to a variety of crops, particularly to those of market-gardening. But, to admit of the greatest possible use from such cultivation, it is advantageous to operate in connection therewith a stock or dairy farm. The crops from the filter beds may, by this means, be partially utilized upon the farm with better results than from direct sales in the market. This surplus land may be fertilized by broad irrigation if found advisable, but in our estimates we have made no allowance for preparing it for this purpose, either by underdrainage or by grading the surface.

Mr. Gray's estimates, both for precipitation and for irrigation, are based upon caring for a dry-weather flow of 9,000,000 gallons of sewage daily, including about 3,000,000 gallons of manufacturing waste; that is to say, while the intercepting sewers and other parts of the work, which cannot be enlarged except at great cost and inconvenience, are made of capacity sufficient for a population of 300,000, or a dry-weather flow of sewage of, say, 24,000,000 gallons daily, those parts of the works which are intended for the treatment of the sewage, and which can easily be extended from time to time as required, are proportioned to a dry-weather flow of 9,000,000 gallons.

In our estimate of the cost of filtration, we have assumed the same basis of sewage flow, and have, as far as possible, adopted the same scale of prices as Mr. Gray, which, as before stated, we consider liberal and safe. For the cost of the whole system of intercepting sewers, which is the same in this as in the precipitation scheme, we have taken Mr. Gray's figures without change, viz., $2,195,973.00. We have further assumed that, as an average through the year, each acre of land, when properly prepared by underdrainage and grading, will dispose of 45,000 gallons daily, this being about the same as the English basis of 1,000 people per acre.

Upon these assumptions, we find the total cost of the scheme for intermittent filtration at Warwick plains, including the purchase of 1,000 acres of land and the special preparation of 200 acres for use as filter beds, to be $4,620,000. Sludge-tanks are provided at the farm to remove from the sewage, by simple sedimentation without the use of chemicals, the solid and slimy matters which would tend to clog the pores of the soil, such removal being, in the opinion of the best judges, necessary to secure the best working of the system of intermittent filtration where so large a quantity is put on the land as is proposed in the present instance.*

The yearly cost of operating, including the expense of pumping the sewage and the care of the sludge, we estimate at $28,000 per year. The subsequent cost of distributing the sewage over the land and the care of the filter beds, as well as the cost of management and operation of the farm, we assume will be repaid by the sale of the products.

As to the expectation of profit from the application of sewage to the land, our opinion is decidedly adverse. Irrigation in dry climates, or even in moist climates if the water be applied only at such times and in such quantities as are needed, is a most valuable aid to agriculture; but where the water comes, and must be cared for night and day, and every day in the year, and in largest quantities in rainy weather when it is needed least, the case is very different. It then becomes more of a hindrance than a help. And whilst there are in England a number of towns, mostly of small size, where sewage farming on the process of intermittent filtration has resulted in a profit, yet in the case of Providence, where the climate forbids the production of any crops for nearly half the year, and where no experience has been gained in such farming, we think our assumption that the cost of distributing the sewage and the management of the farm will be recovered from the sale of its products, is as favorable as it is safe to make.

* See Second Report of Royal Commissioners on Metropolitan Sewage Discharge, 1884; pages xlv., xlviii. Also Bailey-Denton's Ten Years' Experience, etc., etc. Second Edition, page 21.

IV. PRECIPITATION AT FIELD'S POINT.

In this scheme it is proposed to pump the sewage from the main intercepting sewer into tanks located at Field's point, where it will be treated chemically. The clarified effluent will be conducted, by means of an outlet sewer, to a point midway between the shore and Fuller's rock light, where it will be discharged at the bottom of the channel in such manner as to secure the utmost possible diffusion. This is the scheme recommended by Mr. Gray, and for which he has given an estimate of cost in his report of November 14, 1884.

We have made a new estimate of those parts of the work which are intended for the raising, storing, and treatment of the sewage, but as it gives a result not differing materially from Mr. Gray's estimate, we adopt his figures, which show the total cost of the precipitation scheme to be $3,699,504, or, say, $3,700,000.

As to the yearly cost of treatment, it is hardly possible to give exact figures, owing partly to the want of experience in such work in this country, and partly to a want of certainty as to the standard of purity in the effluent that will be required at different seasons of the year. We have, however, estimated the cost of thorough treatment throughout the year of a sewage of average quality, believing that in practice it will be found that a much less quantity of chemicals will be required in the colder months than we have provided.

The yearly cost of pumping and treating the sewage, when the dry-weather flow shall have reached 9,000,000 gallons per day, we estimate at $65,000; believing, however, that in practice this may be reduced to $53,000.

COMPARISON OF THE SCHEME OF INTERMITTENT FILTRATION AT WARWICK PLAINS WITH THAT OF CHEMICAL PRECIPITATION AT FIELD'S POINT.

It remains now to weigh the comparative merits of the two latter schemes, as in our judgment it is between these two that the choice must lie.

And, first of all, to what extent will these two schemes accomplish the end for which they were designed, and free the city from sewage nuisance? For any plan which does not accomplish this should be at once dismissed from consideration.

In answer to this inquiry, our opinion is clear that success may be attained by either scheme.

That sewage may be effectually disposed of by intermittent filtration does not now admit of any doubt. Since this method of disposal was first proposed by Dr. Frankland in 1870, it has been tried in a large number of towns in England, and in a few instances in this country—the principal one being at the town of Pullman, Illinois. In all cases except where the essential requirements of the process have been grossly violated, its success in producing an effluent clear, colorless, and free from all noxious or putrescible matters has been complete. . . .

As regards the particular case in hand, we find the land at Warwick plains to be of a kind well suited for filtration, being very largely sand and gravel with a covering of light soil, so that we have no doubt that, if proper care were taken in the matter of underdrainage and grading the surface, and the sewage applied with proper intervals of rest, it would be thoroughly purified, and the city freed from the nuisance under which it now suffers.

Turning now to the scheme for chemical precipitation at Field's point, we think that this method will also deal effectually with the sewage, and afford a satisfactory solution of the present problem. Precipitation processes have been in operation in England for the last thirty years, and the experience there gained is more than that of all the world besides. A committee appointed in 1880 by the city of Glasgow to investigate the subject of sewage disposal,* sum up in their report the results of experience bearing upon this point as follows:

"There are processes of precipitation now in operation, which give an effluent capable of being discharged into a river with perfect inoffensiveness and without sensibly destroying its purity, provided always that the volume of sewage is small

* See Report Royal Commission on Metropolitan Sewage Discharge, page xxiv., paragraph 169.

compared with that of the river. . . . . Whatever be the process of chemical purification to which the sewage is subjected, the effluent is still impure, and will putrefy and give off noxious gas if kept for some time ; and we know of no way in which the purification can be completed but by oxidation. Filtration through cultivated land, *i.e.*, irrigation, is probably the best means. But oxidation of the effluent may in most cases be effected by the simple and natural process of running it into the nearest water-course, when, if the proportion of clean water be sufficient, the organic matter will be gradually oxidized, and the effluent water will not become putrid or offensive in any way, even in warm weather."

The fact seems to be that the nuisance of sewage is almost wholly due to the suspended matter. If this be taken out by the process of precipitation, dilution with a sufficient quantity of water, usually stated to be twenty times the volume of the sewage, is all that is needed to insure the complete destruction of the organic matters which remain. In the present instance, the large volume of water which passes Field's point is amply sufficient to diffuse and oxidize without offence many times the quantity of clarified sewage which will ever be poured into it.

We have no doubt, therefore, that a precipitation process at this point, properly worked, will so effectually dispose of the sewage that it will cause no further trouble.

In claiming for these two schemes that they will effectually dispose of the sewage, we do not mean to say that there will not, at times, be unpleasant smells in the immediate neighborhood of the works. The pumping station, screening chamber, and the precipitation tanks, as well as the sludge tanks of the filtration scheme at Warwick plains, will, under certain atmospheric conditions, not be free from objectionable odors. With good management there should ordinarily be no smell noticeable outside the works, and even at the worst the trouble will be strictly local. In no case will there be anything detrimental to the public health, nor anything that can be properly called a nuisance.

Both schemes, then, being satisfactory solutions of the problem in hand, and as such substantially equal, we must compare them next from the financial point of view.

As we have already stated, the first cost of the filtration scheme will be $4,620,-000, whilst the cost of the precipitation scheme is $3,700,000, showing a difference in favor of the latter of $920,000.

This, however, is not conclusive. The question of annual cost must also be taken into account.

This is made up of three elements : Interest upon the first cost, operating expenses, and repairs, including in the latter the cost of maintaining and, when necessary, completely renewing such parts of the works as are of a perishable nature. Summing the first two of these elements for each scheme, we get the following :

For the filtration scheme :

Interest upon $4,620,000 at 3½ per cent	$161,700 00
Operating expenses, including pumping and care of sludge	28,000 00
Total	$189,700 00

For the precipitation scheme :

Interest upon $3,700,000 at 3½ per cent	$129,500 00
Operating expenses, including pumping and cost of precipitation	65,000 00
Total	$194,500 00

The third element of the annual expenses—to wit, the repairs and renewals of perishable parts—hardly admits of a satisfactory estimate. It is evident, however, that when we consider the much greater cost of the machinery required to pump to the sewage farm, the larger amount of iron submitted to the action of sewage, and the liability to derangement in a complicated system of tile drainage, that this item of expense will be the greater for the filtration scheme. And when we consider further that the cost of treating the sewage is likely to be considerably reduced below the cost given in the preceding estimate, it seems quite certain that

in the matter of annual cost, as well as in first cost, the balance will be in favor of precipitation.

Another consideration tending, as we think, to incline the scale in the same direction, is the greater simplicity of the organization necessary to carry on precipitation as compared with filtration.

The kind and quantity of chemicals required to produce a satisfactory effluent having been once determined by the experience of the first few months, during which time the greatest care and skill will be well rewarded, the process afterward will be mainly a matter of routine. This will be especially true at Providence, where the effluent will be discharged into a large body of moving water, whereby it will be at once greatly diluted and dispersed. In discharging into small fresh-water streams, where the dilution is small, the character of the effluent has to be much more carefully watched, and, if economy be studied, the treatment varied as

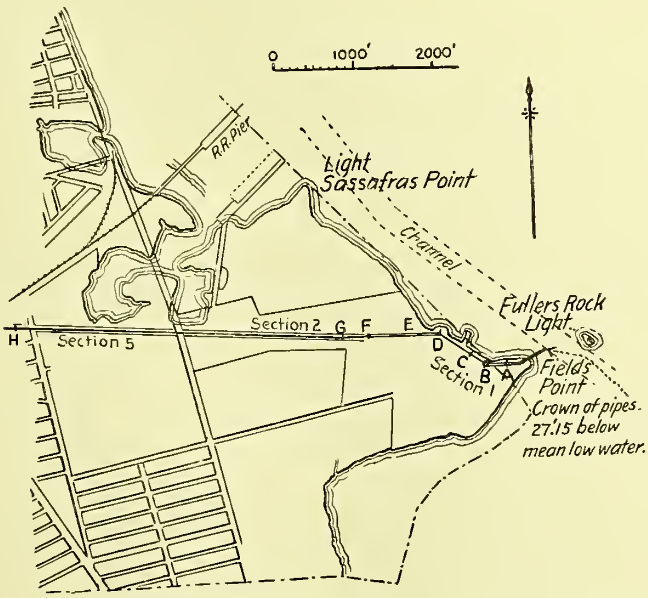


FIG. 64.—PLAN OF OUTLET SEWER TO FIELD'S POINT, PROVIDENCE, RHODE ISLAND.

the character of the sewage varies from the day to the night hours and from season to season. But under the conditions existing at Providence, after the kinds and quantities of chemicals best suited to the local conditions have been once determined and the best methods of manipulation established, the works will need for their successful management only a small force of laborers under the charge of a faithful and intelligent foreman.

The process of intermittent filtration is also in itself, and if nothing but the purification of the sewage be aimed at, one of routine and simplicity ; but when carried on in connection with farming and market gardening, it is no longer a simple mechanical process, but a business venture, which requires for its success the employment and dismissal of many men, the handling of considerable sums of money, and the constant exercise of a skill and foresight of no mean order.

On this subject Mr. Bailey-Denton, who is one of the warmest advocates of the application of sewage to land, and who has done more than all others together to develop and bring into use the process of intermittent filtration, remarks :

"That a sewage farmer, to qualify himself for success, must serve a special apprenticeship to the occupation. Moreover, it has been made clear that an ordinary

farmer is no better qualified to deal with sewage, without such apprenticeship, than a gardener; for not only is it necessary to know what grasses and vegetables can be best treated with sewage, and to regulate the frequency of application and the quantity of liquid to gain the best return, but it is absolutely essential that he should be able to effect the best and readiest sale of his crops when fit for market, and so conduct his operations with reference to the demands of local markets, and of such other markets as he can reach, as will conduce to the growth of only such crops as he can most readily sell. By this means he will reduce to a minimum the losses incidental to all food production; for it is quite certain that, in the long run, the man *who sells the most at the right moment, and who aims at converting into milk or meat what he cannot sell,* is the person who will make the

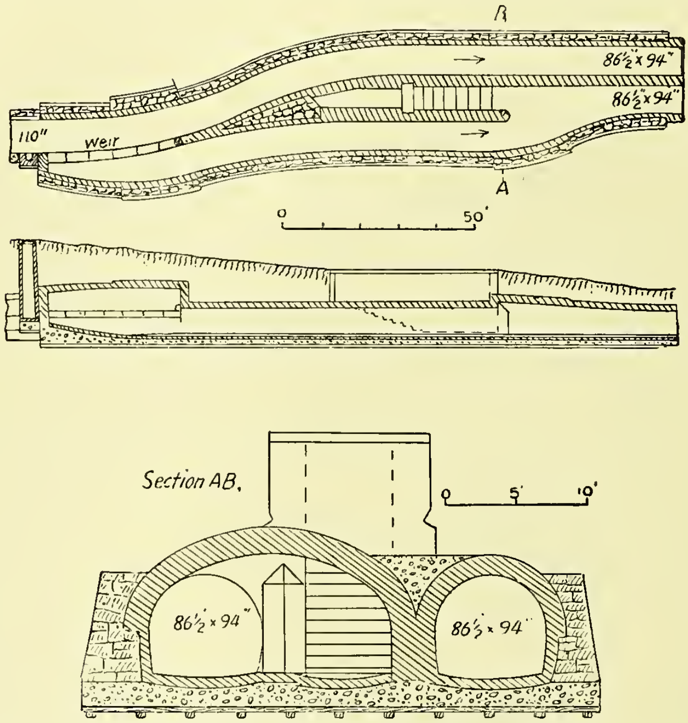


FIG. 65.—SECTIONS OF OUTLET SEWER, PROVIDENCE, RHODE ISLAND.

most money. To do this it is absolutely requisite that every sewage farm should have upon it sufficient buildings to house a proper number of milch cows and pigs, to consume a portion of each season's produce.

"It is essential, in fact, that a tenant of a sewage farm should combine in his own capabilities the practical qualities of a farmer, a gardener, and a market salesman, which will induce him to avoid all treatment of a *dilettante* character, and lead him to embrace in his management the growth of such crops only as will keep him most favorable before the market he serves." *

In other words, to conduct a sewage farm of 1,000 acres is an enterprise calling for a high order of business capacity, and above all demanding a constant watchfulness and study, which experience shows can be expected only where a strong personal interest is at stake, and in which any kind of corporate management is apt

* See Bailey-Denton, on "Intermittent Downward Filtration," edition of 1885, pages 98–99.

to lead to failure. So long, therefore, as another course is open for adoption, we cannot advise the city of Providence to incur the risks which a business undertaking such as this will involve.

CONCLUSIONS.

Summing up our conclusions, we find as follows:

1. That in order to cleanse the rivers and the cove, all sewage must be kept out of them, except in time of storms.

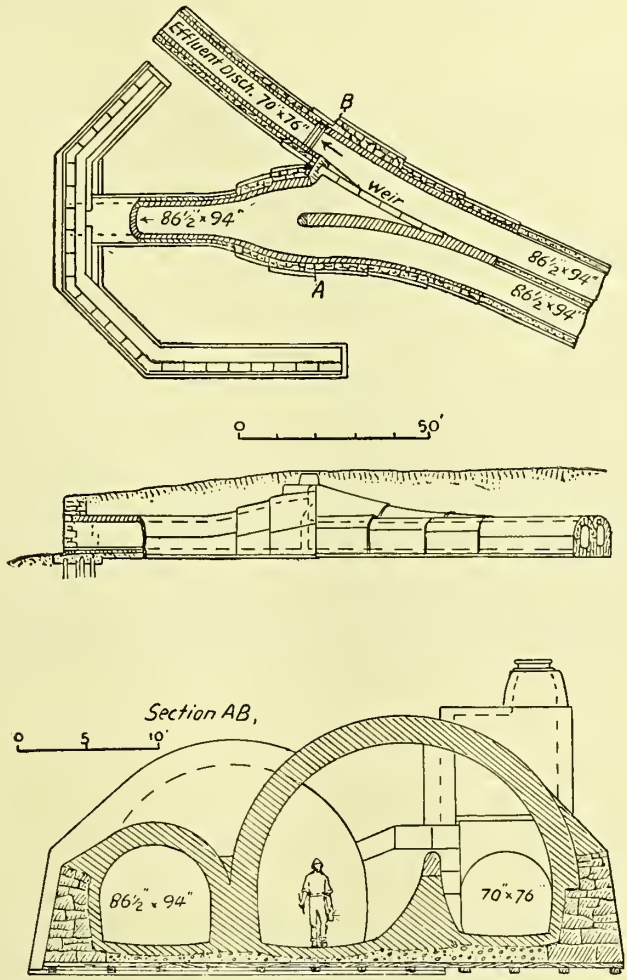


FIG. 66.—SECTIONS OF OUTLET SEWER, PROVIDENCE, RHODE ISLAND.

2. That this can be accomplished only by a system of intercepting sewers, substantially such as that proposed by Mr. Gray.

3. That of the various schemes for final disposal of the sewage, the two which we consider best are those for Intermittent Filtration at Warwick plains, and Chemical Precipitation at Field's point.

4. That either of these will dispose of the sewage in a satisfactory manner, and in a way to free the city from nuisance.

5. That in this respect the two plans are substantially equal.

6. That of these two the precipitation scheme is, in first cost, the cheaper by $920,000.

7. That in annual cost the balance will probably be in favor of precipitation.

8. That the organization needed for precipitation is simple, having in view but a single object—the purification of the sewage.

9. That the organization at Warwick plains will have two objects: one, the purification of the sewage; the other, the somewhat complicated business of conducting a large farm with a view to profit. In other words, it will be a business

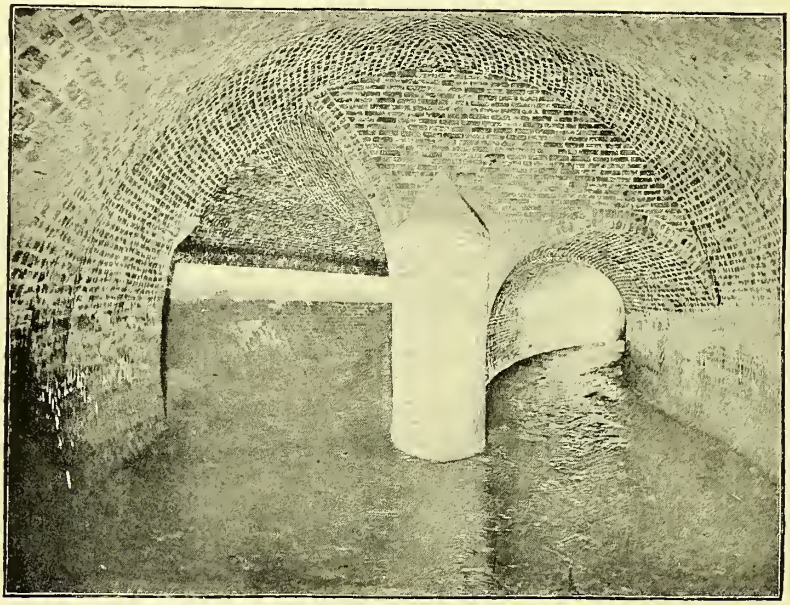


Fig. 67.—View in Storm Outlet, Bell Mouth of Providence Intercepting Sewers.

venture in which the city should not embark unless there be no satisfactory alternative.

10. For these reasons, the scheme of chemical precipitation at Field's point is, in our judgment, the one best worthy of adoption.

Work was begun upon the intercepting sewers in 1890, and to December 31, 1891, 7.388 miles had been constructed. The outlet to Field's point may be seen by reference to the map, Fig. 64. Some of the more interesting details may be gathered from Figs. 65 and 66, the references of which for locations are to Fig. 64. Fig. 67 is a view taken in the mouth of a storm outlet. The proposed precipitation works are to be located on Section 2, near the point F as shown on the map, Fig. 64.

The construction now in process is under the supervision of Mr.

Shedd, who is again city engineer of Providence, having succeeded Mr. Gray in 1890.

In regard to the authorship of the plans of the improved sewerage and sewage disposal works, as being actually carried out at Providence, it may be said that the intercepting sewers are substantially as designed by Mr. Shedd, and as outlined in his report of 1874. The credit of the plan of the sewage disposal works essentially pertains to Mr. Gray. The complete system may be stated, therefore, as the joint work of these two eminent engineers.

CHAPTER XXIX.

BROAD IRRIGATION AT THE WORCESTER, MASSACHUSETTS, STATE HOSPITAL FOR THE INSANE.

THE irrigation works at the Worcester Hospital, which were designed by Buttrick and Wheeler, civil engineers, of Worcester, in 1876, are deserving of brief description in this work, not only because they are, so far as the authors are informed, the first successful irrigation works in this country, but that they have continued to successfully dispose of the sewage of about 600 people, the ordinary population of the hospital, from the date of their completion until the present time. A letter from the superintendent in January, 1892, states that no trouble has ever been experienced in disposing of the sewage of the hospital in the manner which was originally designed.

It is true that some attempt had been made to dispose of sewage by broad irrigation at the State Insane Hospitals at Augusta, Maine, and Concord, New Hampshire, a short time before the sewage farm of the Worcester Insane Hospital was put in operation. Neither of these attempts were, however, entirely successful and both have been abandoned. We may therefore give the credit to the authorities of the Worcester Hospital, of instituting the first successful sewage irrigation farm in the United States.

The hospital building is situated on a considerable rise of ground, about 3,000 feet west of the main irrigation field, shown in plan by Fig. 68, the area of which includes about 14 acres. The several branches of the hospital sewers are all brought to a common point, a few hundred feet east of the main building, and connect in a manhole from which a by-pass leads to a settling tank. The details of this tank are shown by Fig. 69.

At the tank there is also located a windmill by which sewage is elevated when required, and used during the growing season to irrigate the lawns immediately about and adjacent to the building. It is stated that no nuisance has ever resulted from a judicious use of the sewage in this way. The fall from the settling tank to the main irrigation field is about 37 feet, and the pipe sewer leading from the tank to the main field is 12 inches in diameter. At manholes Nos. 8, 10, 11, and 13, Fig. 68, along this pipe, outlets are provided by which sewage can be run as required into main distributing trenches and consider-

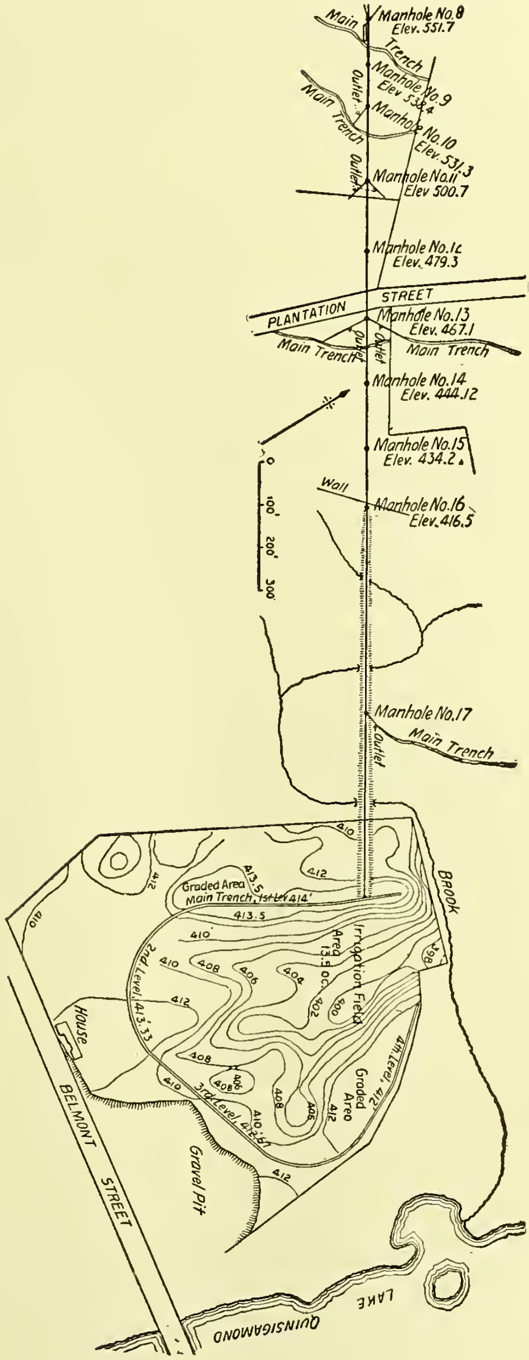


FIG. 68.—PLAN OF SEWAGE DISPOSAL AREA, HOSPITAL FOR THE INSANE, WORCESTER, MASSACHUSETTS.

able additional area of land reached by irrigation. The total area that can be irrigated, including the specially prepared main field, is from 30 to 40 acres. The entire hospital farm includes 257 acres.

The settling tank, Fig. 69, is 30 feet long, 16 feet wide, and covered by arches turned upon iron girders, with side walls and bottom of

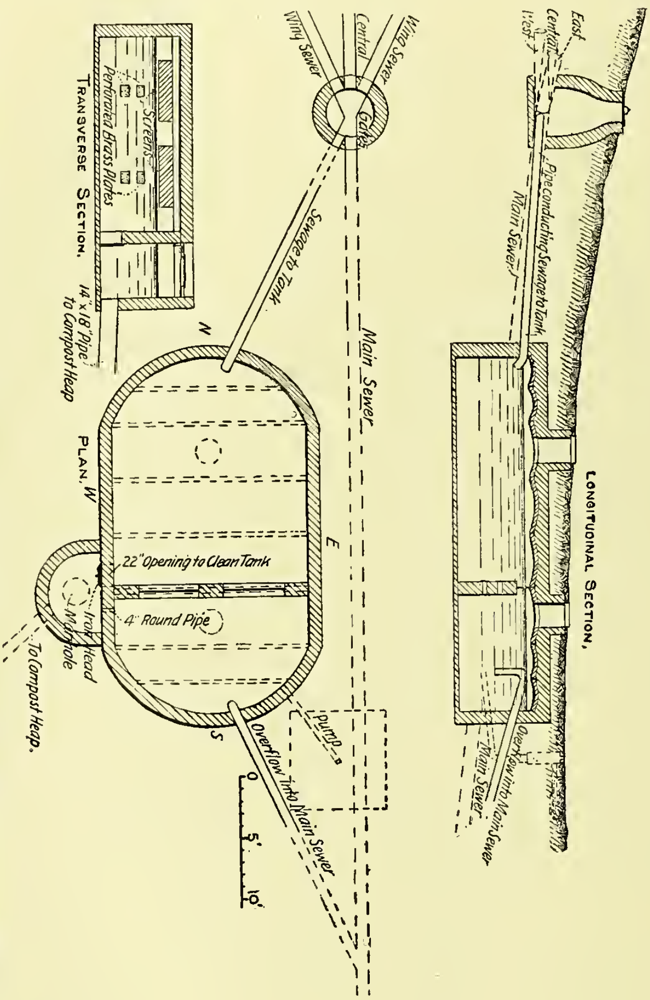


FIG. 69.—SETTLING TANK AT THE HOSPITAL FOR THE INSANE, WORCESTER, MASSACHUSETTS.

brick laid in cement, and made water-tight by a Portland cement plaster coating one-half inch in thickness. The sewage enters the tank at the west end and flows out at the east end, as indicated on the plan. About two-thirds of the distance from the inlet to the outlet a brick partition is built across the tank, in which are placed 4 plates

of brass perforated with 60 holes one-fourth of an inch in diameter. The lower plates are 30 inches from the floor of the tank; the entire partition is 4.5 feet high, and capped with a strong netting of galvanized wire of ½-inch mesh. As stated, the sewage is received into the larger division, where the solids are detained, the fluid portion straining through the brass plates and wire netting and passing to the main sewer to be used for irrigation.

The published reports do not furnish any detail as to just the method used for disposing of the sludge from the settling tank and the frequency with which the tank is cleansed. Definite statements are also lacking in regard to the quantity of sewage per day, quality of the soil of the irrigation area, etc.

The main irrigation field of 14 acres area is provided with a main carrier laid out in four different levels of about equal length. The first level is at an elevation of 414 feet above tide-water; the second at an elevation of 413.33; the third, 412.67; and the fourth level at an elevation of 412 feet. The balance of the details will be readily understood by reference to the plans.

The work was largely constructed by the inmates of the hospital, and no statements of cost can be made.*

* The chief source of information in regard to sewage disposal at the Worcester Hospital is the 47th An. Rept. of the Trustees, etc., for the yr. end. Sept. 30, 1879.

CHAPTER XXX.

BROAD IRRIGATION AND INTERMITTENT FILTRATION AT PULLMAN, ILLINOIS.

In 1880 the Pullman Palace Car Company concluded to erect, in connection with their Chicago Works, a model town as a place of residence for their large number of artisans and mechanics. For this purpose a nearly level tract of land was selected on the west shore of Lake Calumet, at a point between five and six miles west of Lake Michigan and fourteen miles south of the central part of the city of Chicago. The company's large car shops and car-wheel works, employing over 4,000 operatives, are located here, as are also the Allen Paper Car Wheel Works, the Union Foundry, the Pullman Iron and Steel Works, the Standard Knitting Mills, Paint Works, Terra Cotta Works, and the Drop-Forge and Foundry Company's Works. The total number of operatives in these various manufacturing establishments, including the Car Wheel Works, is said to be 5,500.

The town (now a part of the city of Chicago) owes its inception to the president and founder of the Pullman Palace Car Company, Geo. M. Pullman, Esq., who has carried out here an ideal town in which are provided, not only houses for the workmen, but all the various needs of a modern civilized community. The present population is given as 11,000.

The site of the town is almost level, and on an average from 7 to 8 feet above the mean water surface of Lake Calumet. The lake drains only a small area and discharges into Lake Michigan through the Calumet river, which, however, does not flow through the lake, but is connected therewith by a small channel, through which the water flows from lake to river, or from river to lake, according to the varying condition of winds and floods. The lake is about 3 miles long, $1\frac{1}{2}$ wide, and from 1 to 8 feet in depth. The absence of any current in this shallow lake renders it undesirable to make Lake Calumet the disposal place for crude sewage.

The design and construction of the sewerage system and sewage disposal works were entrusted to Benezette Williams, C. E., of Chicago, who, after a review of all the circumstances, determined upon a purely separate system of sewerage, with disposal by broad irrigation supplemented by intermittent filtration, upon a tract of land about three

miles distant from the town. The rainfall is disposed of by a system of drains leading to Lake Calumet by the most convenient lines. Construction upon the sewerage system began in August, 1880, and in October, 1881, the entire system, including the land disposal, was first put in operation. The plans were reviewed by E. S. Chesbrough, M. Am. Soc. C.E., as consulting engineer for the Pullman Company.

The sewerage system proper is, as stated, a purely separate system to which nothing is admitted but sewage, except the small amount of water for flushing from a series of connections with the water mains. Automatic flushing basins are placed on the house drains and receive the sewage from the sinks and wash-bowls, while the water-closet sewage flows directly into the street sewers. The flushing basins also serve the purpose of grease traps, the siphons being so constructed that the grease is carried out whenever a flush occurs. The grease, having become cold while in the basin, does not adhere to the sides of the sewers when rapidly flushed out. From 4 to 6 houses are connected with one basin, as a measure of economy.

The sewers converge to a common point, at which is located a storage reservoir of a capacity of about 300,000 gallons. The ventilation of this reservoir is secured by means of 8 flues, lined with 12-inch sewer pipe, built into the buttresses of the water tower, in the base of which the storage reservoir is located, and opening above the top of the tower at a height of 165 feet. The ventilation is further assisted by a 20-inch pipe leading to the chimney of the car shops. The bottom of the storage reservoir is about 30 feet below the surface of the ground, and the top of the groined arches covering it 10 feet below the surface of the ground. The pumping engines are two direct-acting compound condensing engines, with piston pumps. Each has a capacity of 2,500,000 gallons in 24 hours. They are located in an engine-room, directly over the storage reservoir previously described, the floor of the engine-room being supported by the groined arches which cover the reservoir.

The daily average quantity of sewage for 1890 was 1,800,000 gallons, of which it is stated that about 1,375,000 gallons was from the dwellings and the balance from the shops. In September, October, and November, 1890, the average daily quantity of sewage pumped was a trifle over 2,000,000 gallons.

The yearly amounts of sewage pumped for the ten years, 1882 to 1891 inclusive, were as follows :

Year.	Gallons.	Year.	Gallons.
1882	211,620,160	1887	573,700,640
1883	358,354,520	1888	568,607,760
1884	443,815,480	1889	602,250,000
1885	468,302,120	1890	657,001,360
1886	472,748,080	1891	617,664,030

During the first nine months of 1892 a total of 513,996,060 gallons of sewage was pumped, or an annual rate of 685,328,000 gallons.

It was considered desirable to avoid screening or settling the sewage before pumping, and with this object in view the pumps were designed with special reference to pumping everything which might be found in the sewage. For this purpose a rubber valve of special make

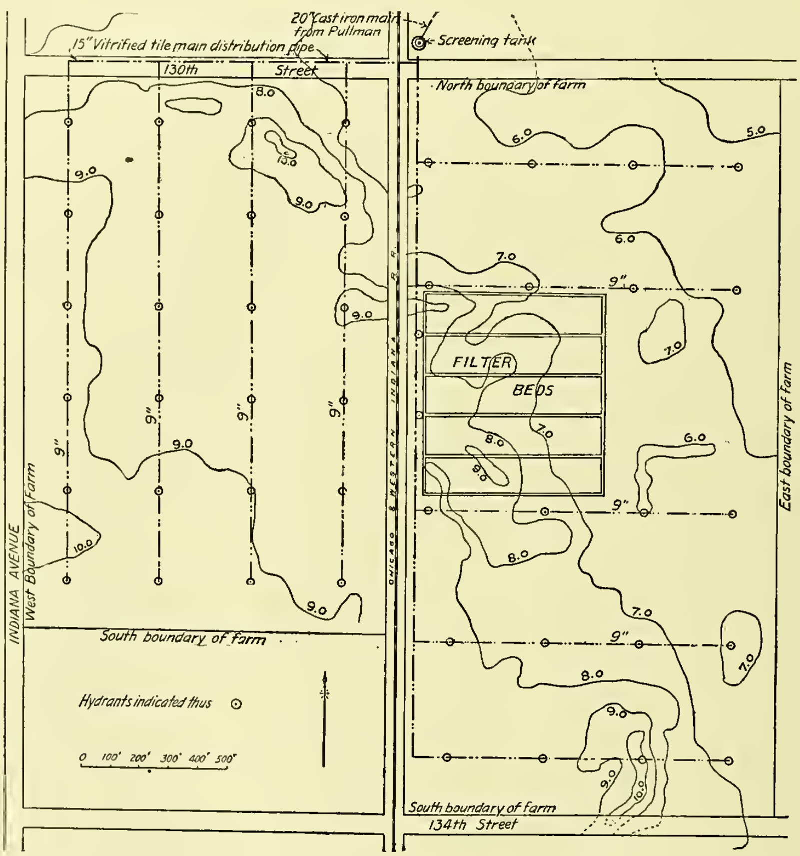


FIG. 70.—PLAN OF SEWAGE FARM AT PULLMAN, ILL., AS LAID OUT IN 1880.

is in use, which is stated to work satisfactorily. Cotton waste, cloths, sticks and blocks of wood pass through the pumps frequently, without injury or inconvenience. Whatever sediment collects in the reservoir by incidental settling is washed loose with a hose from time to time, and passed through the pumps with the sewage. The pumping plant was furnished by the Cope & Maxwell Manufacturing Company, of Hamilton, Ohio.

The cost of operating one of the pumps for 20 hours a day and

pumping an average of 1,800,000 gallons per day in 1890 is stated as follows:

Fuel	$1.73
Oil and waste	0.57
Attendance	3.75
Total	$6.05

This would be at the rate of $3.36 per 1,000,000 gallons pumped. The actual lift, not including friction in the force main, is on an average about 30 feet.

A 20-inch cast-iron main, nearly 3 miles in length, connects the pumping station with the sewage farm. At the farm end of this main is located a closed screen-tank, as indicated on the plan, Fig. 70, fitted with a screen of ½-inch mesh. This tank is 6 feet in diameter, 24 feet long, and made of ¼-inch boiler-iron. The lower end is high enough above the floor to admit of wagons being driven under it, and into which may be received the material intercepted by the screen, by the opening of the valve at the lower end of the tank. A section through the screening tank is shown by Fig. 71.

The distribution pipe, leading from the screening tank, is fitted with a pressure regulator set to 10 pounds. An overflow pipe is also provided as an additional precaution. The object of the pressure regulator is to prevent heavy pressures and vibrations from the pumps from coming upon the distribution pipes, which are entirely of vitrified tile. The main distribution pipe is 15 inches in diameter, with 9-inch laterals 315 feet apart. Hydrants are located on the 9-inch lines every 320 feet, thus giving one hydrant to about each 2⅓ acres. The distribution pipes of vitrified tile were tested with water pressure before laying.

The system of underdraining consists of parallel lines of common agricultural tile, 2 to 4 inches in diameter, laid to an average depth of 3½ feet and about 40 feet apart. According to a statement made by E. F. Martin, farm superintendent in 1887, the primary drains would give better service if they were all at least 4 inches in diameter. The small drains connect with a main underdrain, from 6 to 12 inches in diameter, which empties into a ditch discharging into Lake Calumet.

The tract of land originally appropriated to sewage disposal comprises about 1,500 acres, and at present about 140 acres are in use for this purpose. Of this amount, 15 acres were laid out in flat beds, surrounded by embankments in order to permit of use for intermittent filtration whenever necessary. The soil is the ordinary Illinois prairie black alluvium, 1 foot in depth, underlaid by clay with occasional pockets of sand. The distribution after the sewage leaves the hydrants is effected by means of short pieces of hose connected with the hydrants, supplemented by temporary shallow grips or furrows, as

needed for the different crops. The most satisfactory crops have been found to be cabbage, cauliflower, celery, asparagus, onions, sweet corn, squashes, and other vegetables common to market gardening. The raising of potatoes has been found to be a failure on this farm.

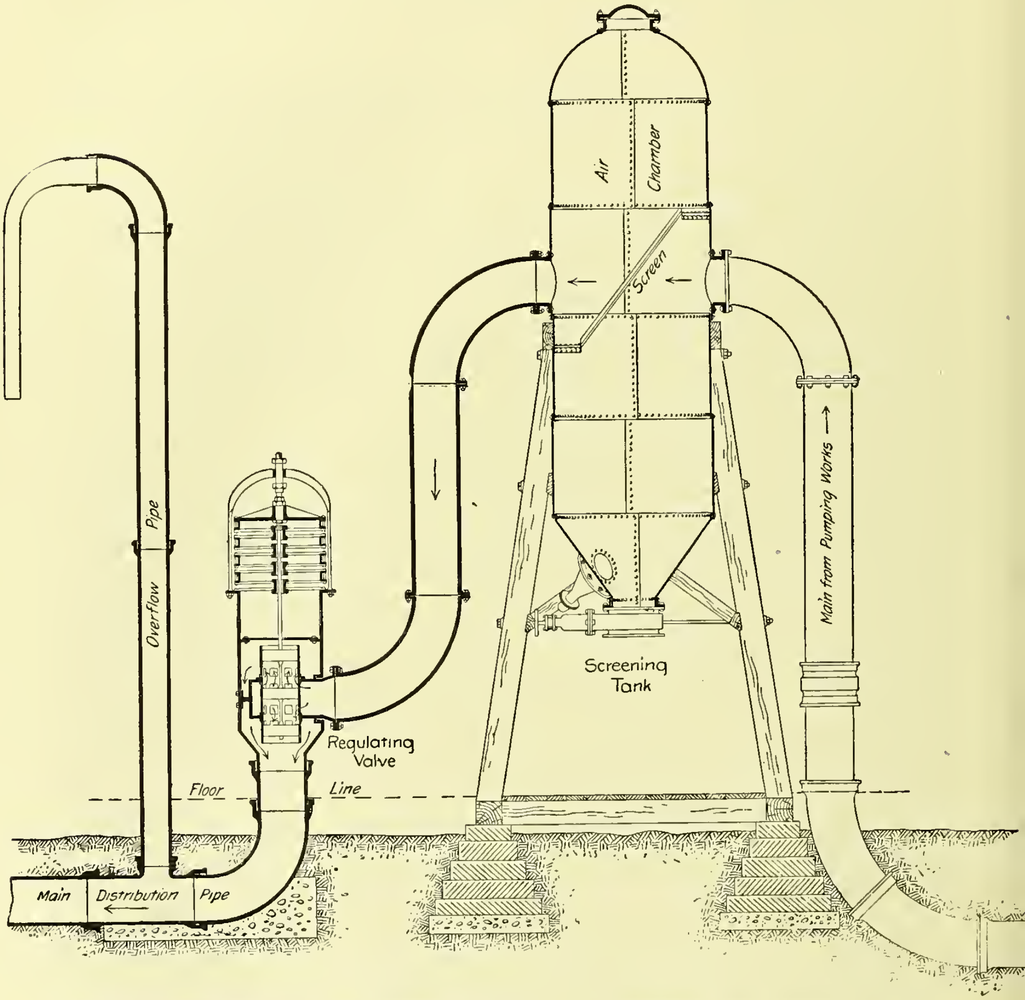


FIG. 71.—SECTION THROUGH SCREENING TANK AND PRESSURE REGULATING VALVE, AT PULLMAN, ILLINOIS.

Italian rye-grass is also unsuited to the soil of this farm; it is stated to grow so coarse and rank as to be nearly worthless for feeding Very little stock is kept, for the reason that it is more profitable to raise vegetables, etc., for the Chicago market.

A plan of the farm as laid out in 1880 is shown by Fig. 70.

Many statements were made in the earlier years of the operation of the Pullman farm as to the large commercial profit realized. All such that have come under the authors' notice have lacked definiteness as to the detail. The most authentic statements indicate that in some years the farm proper has yielded a net profit of as much as 8 per cent. on the investment, while in other years, owing to early frost or other adverse causes, there has been very little or no profit. The positive statement is made, however, that in no year has the outlay exceeded the income. During the growing season about 40 laborers are employed, this number including those who attend to the irrigation. During the balance of the year the labor at the farm, which is mostly confined to controlling the distribution of the sewage, is limited to one or two men. The statements of net profit in the foregoing are made without reference to the cost of pumping the sewage, which, from what has already been stated, may be taken at about $2,208 per year.

The Pullman management has not kept any record of the temperature at which the sewage reaches the disposal area in winter, but it is stated to leave the houses at an average temperature of 65° Fahr. The minimum winter temperature of the air is − 25° Fahr. The maximum snowfall is about 2 feet ; in the ordinary winters it seldom exceeds 1 foot. The maximum depth of frost penetration is stated at 3.5 feet; the ordinary depth, 2 feet.

Mr. Duane Doty, engineer for the Pullman Company, states that the only analysis of sewage and effluent in his possession was made in the laboratory of the State Board of Health of Massachusetts, November 30, 1887, as follows, an analysis of water from the farm well being appended :

	Ammonia.			
	Free.	Albuminoid.	Chlorine.	Nitrogen.
Pure sewage	2.3000	.3200	1.98	None.
Filtered sewage from manhole on filter-bed	.8500	.0480	2.31	1.560
Filtered sewage from mouth of main underdrain	.0026	.0108	3.78	.650
Water from farm well	.0900	.0166	1.78	.033

The efficiency of the purification at Pullman has been the subject of considerable discussion, especially in relation to the results attained in winter ; and the following statements by engineers who have visited the farm on tours of inspection are of considerable interest. Eliot C. Clarke, M. Am. Soc. C.E., says : *

The winters at Pullman are colder than in most parts of Massachusetts, but irrigation has always proceeded there without interruption. I made a visit to that farm in February, 1885. For the five days previous the mercury had not risen to 0 Fahrenheit, and had been as low as −25°. On the day of my visit, the mercury standing at −12°, I found the sewage going on to the land, and covered by a stratum of ice from one to eight inches thick. I broke the ice, and with a spade dug a hole in the ground below, which was perfectly open. As the weather moderated the sewage rapidly melted the ice above it.

* Report to the Massachusetts Drainage Commission of 1885, p.129.

The second account is by Charles A. Allen, M. Am. Soc. C.E., as follows: *

Upon the day of our visit [January, 1887] it was quite warm, the thermometer registering 40° Fahr. We found that the sewage was all being discharged upon the filtration area, the first section of which was covered with sludge to a depth of about a foot. The sewage was running over this to the second section, which was partially covered with ice, and then over the remaining area, which was entirely covered with ice, and was finally discharged into the effluent trench without having been filtered in the least.

The entire area was completely covered with sewage, and there was evidently no filtration taking place, as about the same quantity passed off at the lower end of the beds as was discharged upon the upper end.

The manager of the farm was away, but we were given the following facts by his assistant, which we subsequently verified:

The farm is run for the purpose of making money, the purification of the sewage being a secondary consideration.

During the summer months when vegetation has received all the sewage it will bear, it is simply turned into Lake Calumet in its crude state.

We were told that not a particle of sewage has been applied to the farm proper this winter, it all having been simply passed over the area as already described.

Mr. Geo. H. Benzenberg, M. Am. Soc. C.E., wrote as follows on Nov. 21, 1892: †

I have not been at Pullman for a number of years, and hence cannot give you any information whatever as to what they are doing there now, but I know that as early as prior to 1887 a large amount of crude sewage was run into Lake Calumet. This I found to be the fact upon a visit to the farm, and which the superintendent finally admitted and excused by saying that it was necessary in order to save the crops. The sewage was being run in a large open ditch, covered by bushes growing on each side, from near the farm to the lake.

Mr. Benzenberg's statement has been corroborated by Mr. Rudolph Hering, M. Am. Soc. C.E., who visited the farm in 1886, and also in 1887.

In 1891 Mr. Allen Hazen, chemist of the Lawrence (Mass.) Experiment Station, visited Pullman. Mr. Hazen's account of his visit, together with an interesting mechanical analysis of the surface soil of the filter beds, is as follows: ‡

I visited the Pullman sewage farm in October, 1891. The superintendent was absent, and I was shown about by a man who had worked on the farm for some years. He told me that with the application of sewage, worms developed in the soil and destroyed the crops, and for this reason no sewage had been applied for two or three years. . . . .

The filter was not in use at the time of my visit, nor did it have the appearance of having been used. My guide thought that it was at least a month since any sewage had been applied, and a much longer time since any considerable quantity had been treated. The sewage of the entire town was being turned directly into Lake Calumet, from which large quantities of ice for Chicago are cut.

* From Mr. Allen's Report of 1887, p. 44.

† Eng. News, vol. xxix. (Jan. 12, 1893), p. 27.

‡ Eng. News, vol. xxix. (Jan. 12, 1893), p. 28.

A sample of the surface soil of the filter had the following mechanical analysis:

	Mm.		Per cent.
Finer than	.24		87
" "	.12		42
" "	.06		28
" "	.03		16
" "	.01	organic,	8

Albuminoid ammonia, 225 parts in 100,000.

The analysis shows the material to be very much finer than the sands successfully used in Massachusetts, and it would hardly be possible to put upon it, with good results, any large volume of sewage.

Mr. Doty furnished the following statement in this connection, which he gave as the language of the superintendent of the farm: *

The sewage when not needed upon the fields of the farm is run on to the filter beds, and these filter beds are ploughed up four or five times a year so as to loosen the soil and expose as much of it as possible to the air. At times all the sewage is used upon the farm, and in wet weather not more than half of it. Some seasons have taken all the sewage upon the fields. At rare intervals only, when it has been necessary to clean the receiving tank at the farm end of the iron main, is raw sewage run into Calumet lake, and then for very brief periods and not enough of it to do any harm.†

* Eng. News, vol. xxix. (Jan. 12, 1893), p. 27.

† In addition to those quoted, the further sources of information in regard to the Pullman sewage farm which have been drawn upon are:

(1) The Pullman Sewerage, a paper by Benezette Williams, Member of the Western Society of Civil Engineers, in Jour. of the Assoc. of Eng. Socs. vol. i. (1882), pp. 311–319, from which the main facts in the foregoing in relation to original design of the sewerage system, sewage farm, straining tank, etc., have been abstracted. An abstract of Mr. Williams' paper may also be found in Eng. News, vol. ix. (1882), pp. 203–204.

(2) Tabulation of sewage irrigation statistics, in Mr. Gray's Providence Rept. of 1884.

(3) Articles in Eng. & Bldg. Recd., vol. vii., p. 35; vol. ix., p. 476; vol. x., p. 360; vol. xiv., p. 55.

(4) Private letters to the authors.

(5) Articles in the Sanitary News and the American Architect.

(6) Description of a visit to Pullman by Dr. Wm. Oldright in 6th An. Rept. Prov. Bd. of Health of Ontario (1887), pp. lxxxiv.–vi.

(7) Article "Scientific Sewerage," in the Pullman Journal, Feb. 21, 1891. By Duane Doty, C.E.

CHAPTER XXXI.

BROAD IRRIGATION AT THE MASSACHUSETTS REFORMATORY, CONCORD.

The sewage of this institution was originally discharged into the Assabet river at a point immediately opposite the institution. The deposit of floating and suspended matter of the sewage along the banks and on the bottom of the stream having become noticeable, an attempt was made to screen out the solid portion through coarse wire screens located in a subterranean screen-pit, which was situated near the line of the main sewer and connected therewith by a by-pass. This still permitted the liquid portion of the sewage, with its soluble constituents and much of the finer suspended matter, to be discharged into the river as before. The arrangements for removing the solid portion from the screen-pits were inconvenient, and their non-removal led to the production of a positive nuisance. The clogging of the screens also rendered it necessary, in order to allow the flood flow to pass, either to open the gates of the main sewer so that the sewage would flow directly into the stream without passing into the screen-pits, or else to raise the screen and allow the accumulations of sludge to be flushed out into the river by storm flow.

The sewage proper from the main group of prison buildings amounted to upwards of 100,000 gallons per day, and in times of rainfall this amount was augmented by the roof-water.

The waste water from the gas-works, originally discharged into the common drains, had been afterwards excluded therefrom and allowed to run into an open sink-hole in the gravel, in the rear of the buildings.

The drainage from the sinks and water-closets of a large isolated shop, which has since been removed, was disposed of by flowing in an open ditch leading from the shop to a sink-hole about 70 feet distant.

The waste liquors from the dyeing-vats in the hat-shop, amounting to from 40,000 to 70,000 gallons per day, was further disposed of by allowing it to flow out upon the surface of the ground and into gravel and sand-pits near by, where it was left to soak away as best it might.

Finally, the sink drainage from 10 houses on Commonwealth ave. (see Fig. 72), occupied by the officers and their families, was discharged by a pipe sewer into a large cesspool. The cesspool re-

quired cleaning about once each week, involving an amount of labor equal to the total expenditure of six months' time of one man throughout the year. Water-closets were not introduced into these houses

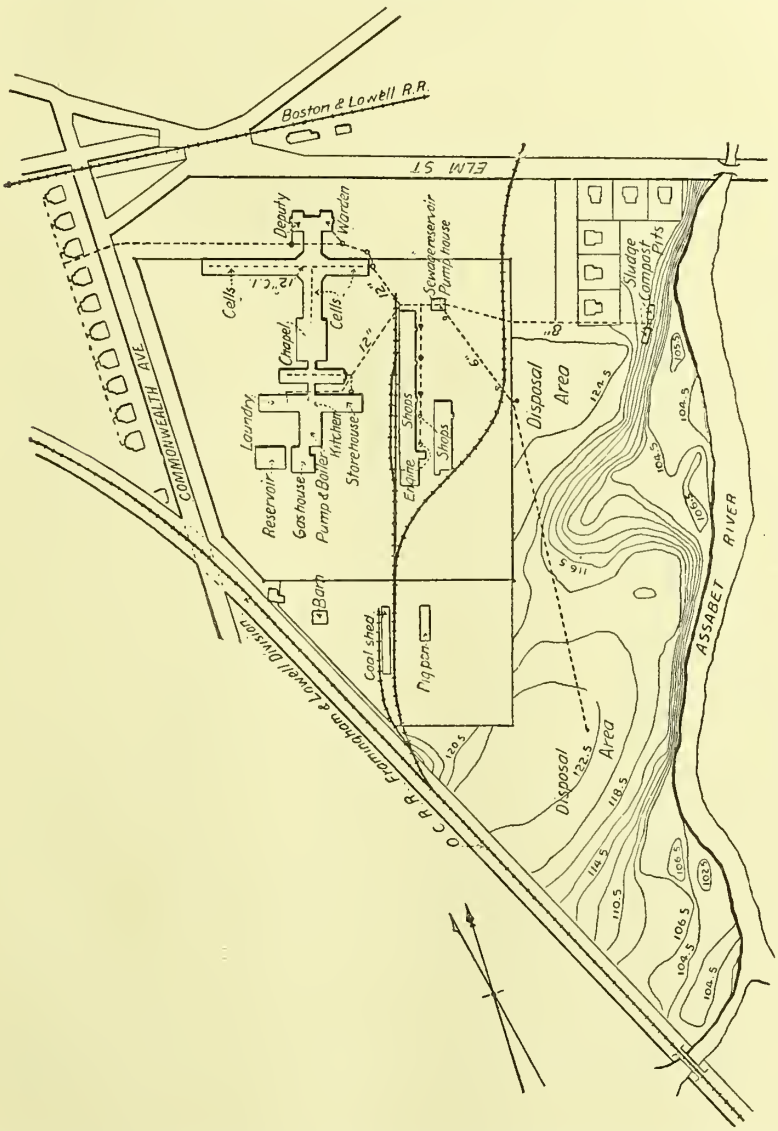


FIG. 72.—PLAN OF DISPOSAL WORKS, MASSACHUSETTS REFORMATORY, CONCORD.

until 1885, and previous to that time each house was provided with a privy.

In the spring of 1883, an Act was passed by the Massachusetts Legislature, authorizing the expenditure of a sum not exeeeding $5,000

for the disposal of the sewage at the Reformatory; and in June of that year the Prison Commissioners instructed William Wheeler, C.E., to prepare plans for a comprehensive system of sewage disposal. Surveys were immediately made and plans prepared and submitted to the Commissioners, who, after accepting them, referred them to the State Board of Health for approval, in accordance with the Act. The State

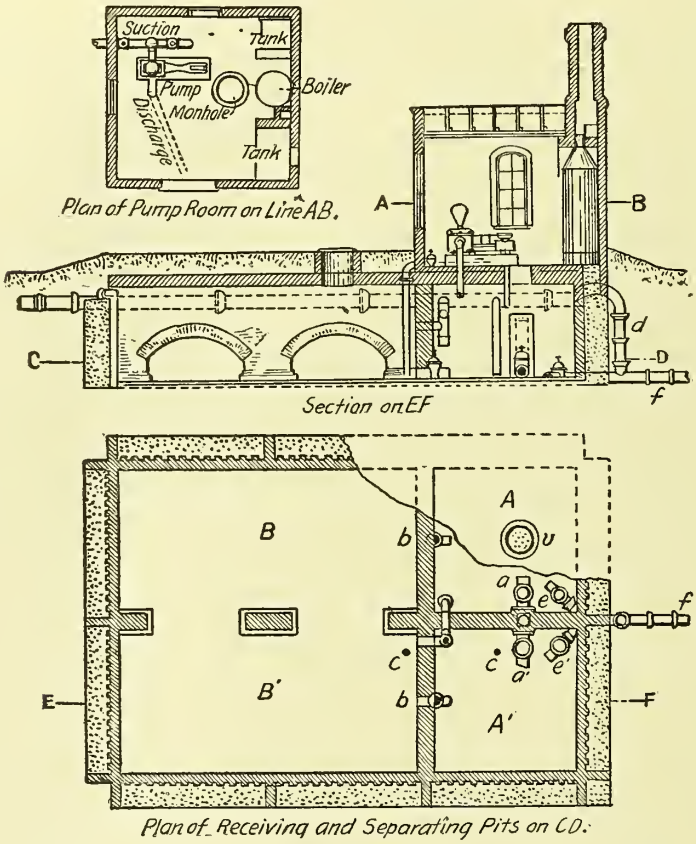


FIG. 73.—DETAILS OF RECEIVING AND SEPARATING TANKS, MASSACHUSETTS REFORMATORY.

Board of Health, after some changes in the selection of the lands upon which the sewage was to be disposed of, approved the plans September 1, 1883. The construction of the works was begun on September 18, and mostly completed during the following summer.

The common labor and much of the skilled labor was done by convicts.

The general arrangement of the new works is shown by Fig. 72, while Fig. 73 represents the principle features of the receiving and

separating tanks, pumping station, etc. The plant has been described as follows:

The plan of the new works, while leaving substantially unchanged the general arrangement of plumbing and interior drains, involved the construction of an entirely new system of pipe sewers outside the prison buildings, from which storm water is excluded except at a few points for flushing purposes, as later described, and whereby all the ordinary sewage is carried to a series of underground receiving and separating tanks or chambers. These chambers are separated by brick partitions sixteen inches thick, laid in hydraulic cement mortar, the outside walls consisting of an eight-inch brick lining or interior facing, with an impervious backing of hydraulic cement concrete or beton, constructed *in situ*, after the brick was laid. Every alternate brick in alternate courses is a header, projecting outward half its length, thus affording a perfect bond between the brick face and concrete backing. The whole is built upon a concrete foundation extending over the entire area of the chambers, affording a tight floor three inches thick and footings six inches thick under all walls and partitions, and is covered by two arches whose adjacent skew backs rest upon a middle partition and piers, thus forming a valley which affords a passage for the main collecting sewer and safety-overflow pipes.

The chambers are provided with sewage inlets, sludge outlets, and suction pipes for discharging the liquid portion, all in duplicate, and each one in a separate compartment from, and capable of being used interchangeably with, its companion. Access to each compartment is had through man-holes of ample size.

The sewage is commonly first admitted through an inlet valve, *a*, into a compartment, *A* (see "Plan of Receiving and Separating Pits," Fig. 73), about twelve feet square, from which, when filled to a depth of five feet, the liquid portion overflows automatically from its middle depth, through an unsealed three-legged siphon, *m*, into another chamber of the same size, *A'*. The second compartment, *A'*, has connection through a valve, *b*, with a storage chamber about twenty-five feet square, *BB*, into which the liquid portion flows in the usual operation of the works, the said liquid portion being pumped out daily through either or both of the suction pipes, *c* and *c'*, as circumstances may require.

The second chamber, *A'*, is practically a duplicate of the first one, *A*, and may be used interchangeably with either the first one as the primary receiving and separating compartment (in which case the crude sewage is admitted through an alternate inlet valve, *a'*); or with the larger one, *BB*, as a storage chamber and pump-well; or, as ordinarily used, in open connection therewith, it affords simply an addition to the storage capacity of the works.

With this interchangeability of uses, effected by simple devices, the function of each compartment may be performed by one of the other two, whereby each may in turn be left in temporary disuse, thus facilitating the work of discharging the sludge, and the examination, repair, and general care of the works.

By causing the liquid overflow from the receiving chamber to take place from the middle of its depth, the solid matter, which either floats or sinks, remains in the chamber, where it is allowed to accumulate until it approaches the level of the inlet of the overflow pipe or siphon. The sludge is then discharged by gravity through the valve, *e* or *e'*, as the case may be, an eight-inch Akron pipe, *f*, into a composting pit situated about six hundred feet distant, on the low bluff overlooking the river. Here the excess of liquid that flows out with it is allowed to leach away into the dry, porous soil, and the residue is covered (at intervals of about two or three days) with a light layer of dry loam, muck, or other absorbent, whereby it is rendered odorless and innocuous, and its fertilizing value developed and preserved. Before the next discharge is to occur, it is in suitable condition to be carried away and composted with more absorbents, or applied directly to the land, with results which demonstrate its agricultural value. In practice, with the present population served by these works, numbering about 650 convicts and upward of twenty officers' families, and disposing of about 100,000 gallons of sewage daily, the sludge is discharged once in two weeks. The accumulations of that period furnish a deposit of from eighteen to twenty inches deep upon the bottom of the receiving chamber, and floating matter to a thickness of from six to ten inches upon

the top of its contents. After a thorough agitation with a pole, through a man-hole, during which about one-half to three-fourths of the floating matter sinks, the discharge valve is opened and the entire contents gravitate into the sludge-pit, which has been made ready by cleaning out the preceding charge, and loosening up the bottom to facilitate the leeching away of the excess of liquid as already described.

Two open sludge-pits, each about 12 × 40 feet, were originally constructed, to be used alternately; but one has recently been found to serve the purpose, after covering it with a substantial building to exclude rain and snow, and to confine the odor occurring temporarily during the flow of the sludge into it. Although situated within from 150 to 400 feet from six double houses occupied by officers of the prison, the resident engineer states that no complaints have arisen therefrom since it was so housed.

Over one of the small compartments, *A'*, of the receiving chambers, a small pump house is built, the walls of the compartment constituting the foundations of the building. (See "Plan of Pump House," also "Vertical Section on E F," Fig. 73.)

The pump room contains a small Knowles tank sewage-pump, having its steam cylinder eight inches and plunger ten inches in diameter, with a twelve-inch stroke, and connected with an upright tubular boiler thirty-six inches in diameter and seven feet high—both pump and boiler being constructed expressly for these works. The pump has two suction pipes, *c* and *c'*, whereby the sewage may be pumped directly from either chamber, *A'* or *BB*, whence it is delivered through a six-inch iron force-main to the various points at which it is to be disposed of by irrigation. It is discharged through common fire hydrants made with one specially large nozzle and two hose nozzles of ordinary size. Two sewage hydrants are placed within the prison yard, where large quantities are used for the irrigation of its sandy soil, and two more outside the enclosure upon the highest points of the arable land of the prison farm, and at distances of about 400 and 600 feet from the driven wells.

Here the sewage is used in broad irrigation upon such desirable crops as are best fitted for cultivation therewith—chiefly grasses and grains, as well as general tilled crops to a limited extent. The soil, being light, free, and sandy, with the natural water-table at a considerable depth below its surface, is eminently well adapted to receive the sewage, which it does with great benefit to itself, and without complaint of odor or appearance of disagreeable results of any sort; and this notwithstanding the fact that the methods pursued for its distribution are still somewhat crude. The sewage is received at an elevation of several feet above the ground, into a line of wooden troughs supported upon light "horses" or portable trestles, graduated in height so as to secure a suitable fall toward the points of final discharge, and is often allowed to run two weeks, during the hours of pumping, in one place without change.

Undoubtedly a more convenient and economical, and certainly a more sightly management of the sewage, would be effected by suitably grading the surface of the utilization grounds, and constructing shallow open conduits and surface channels, provided with suitable contrivances for deflecting the flow toward any desired part of the field, and through which the sewage would be distributed by gravity and regulated at pleasure.

The inconvenience of moving the present arrangement of troughs and trestles affords a potent temptation to unduly prolong the time of flow in a single place. The duration of flow in one place, under the more convenient system of distribution, could wisely be limited to not more than four days, on even so free and dry a soil; and while the works were not originally so constructed by reason of an inadequate appropriation, later recommendations for reforming the methods of distribution in accordance with the foregoing suggestions have been made to the commissioners, with the offer of gratuitous professional assistance in carrying them into execution. The absence of any particular sanitary motive or necessity, however, for pressing such improvements, may perhaps be held to be a reasonable excuse for neglecting to make them.

The new drains, with a minor exception, are laid in straight lines, with a man-hole at every junction and at every change of direction or grade. The ventilation of the sewers is insured by the admission of air through perforated covers upon certain of

the man-holes, whence it circulates to and through the soil pipes which are carried through the roofs of the prison buildings—the soil pipes of the "strong rooms" also having been so extended in conjunction with the work done under the Act of 1883, with the direct result of entirely obviating the presence of objectionable odors and sewer emanations which had occasionally existed before.

The ventilation of the receiving and separating works is effectually accomplished, without objectionable results of any sort, by the constant admission of air through a perforated man-hole cover, *v*, into the primary receiving compartment, *A*, and its positively induced circulation through a series of openings connecting all the compartments above the level of the sewage therein, and leading, by a suitable arrangement of dampers at the base of the furnace, into either the fire-box under the boiler, or the chimney directly over the boiler, where the gases may be burned—the draught of the chimney in either case effecting the necessary circulation.

The officers' houses upon Commonwealth row were furnished with water-closets, and together with the Warden's and Deputy-Warden's (now Superintendent's) houses, were connected with this system of works during the months of August and September, 1885, through sewers shown upon Fig. 72—the expense for this addition being paid out of the general appropriation for the Reformatory.

Storm water is excluded from the new sewerage works, except in the case of that admitted for flushing purposes by the conductors upon the two houses at the heads of the Commonwealth row sewers, and also through connecting conductors near the heads of some of the principal drains within the prison yard.

To prevent any back-flow of sewage, in case the contribution of storm water by these connections should be excessively large during the night, when the pumps are not ordinarily in operation, a safety overflow, *d*, is provided, whereby the excess automatically escapes into the sludge-pipe, and thence passing by the sludge-pits, is discharged into the river. No considerable quantity of objectionable refuse can so reach the stream, however, inasmuch as such overflow takes place, as already stated, at night, when not only is the amount of normal sewage at its minimum, but the overflow itself consists of the secondary contributions of the storm water, after its primary flow has cleansed the sewers and discharged its scourings into the receiving chambers.

With the present consumption of water, amounting, as already stated, to about 100,000 gallons per day, the night flow of sewage from about 5.30 P.M., when pumping usually ceases, to 7 A.M., when it begins again, fills the sewage reservoirs to within about a foot of the overflow level, or from 80 to 85 per cent. of their full capacity of about 28,000 gallons. The pumping continues from about 7 A.M. to 10.30 A.M., and again from 3 P.M. to 5.30 P.M. daily, at which time it is left empty, ready for the night flow. The large consumption of water and consequent delivery of sewage during the night, and indeed at all hours of the day, is largely due to the practice by a large number of the convicts of so placing a small bit of wood or other material under the seats of their water closets as to cause it to flow with a constant stream, thus maintaining a sense of cleansing and purifying efficacy which is only imaginary, at the expense of a considerable waste of water and the disposal of it in the form of sewage.

The winter care and management of the sewage does not differ in any essential degree from that at other seasons of the year, nor does it present any peculiar difficulties or annoyances. The comparative warmth of the sewage enables it to find its way into the ground before freezing to any injurious extent, while the sludge-pit, being covered by a close house in which a quantity of dry absorbents is stored, is managed without difficulty.

All labor required in the management and operation of these works is done by convicts. The annual expense of running them may be approximately stated as follows—the labor being rated at what would be its fair valuation under normal conditions of employment:

55 tons soft coal, at $4.00	$220 00
Salary of attendant	600 00
Repairs and sundries	80 00
	$900 00

The cost of taking care of the sludge-pits and utilization grounds would be additional, but it is doubtless more than repaid by the purely agricultural value of the sewage products to be cared for and disposed of under any rational system of treatment.

Most of the conductors disconnected from these works have been reconnected with the old brick sewers, whereby a complete double and separate system of sewerage is provided—the storm water thus finding its way into the river.

The dye refuse and washing water from the hat shops, amounting to about 50,000 gallons daily, was disposed of by an independent method, having been collected and carried by a six-inch pipe sewer into a pair of open filter beds or sinks, containing each about 500 square feet, and situated on the slope of the bluff east of the prison yard, where it soaked away without unsightly or unpleasant consequences. These beds or sinks were made in duplicate, to enable the bottom and sloping sides of either one to be raked over, and the nearly impervious deposit of felting fibre thereon to be removed, while the other was in use. The removal of the hat industry last year led necessarily to the abandonment of this branch of the works, which is not therefore shown upon the accompanying plans.

The water from the purifiers of the gas-works, under an arrangement made by the resident engineer of the Reformatory, flows into an open rectangular pit behind the gas-house. Across one end of the pit is a brick partition having an opening through it below the level of the liquid standing therein. The gas liquor first enters the larger compartment, where the oil and light combustible compounds which are brought along with it gather upon its surface and remain therein, while the water itself flows through the submerged opening in the brick partition into the smaller compartment. From the latter it flows out through a submerged pipe orifice into a drain leading into one of the old brick sewers, and thence into the river. The combustible supernatant matter remaining in the larger compartment is regularly burned off twice a month.

The removal of the picture moulding shop, which was in contemplation at the time of building the new works, has since been carried into effect, thus taking it out of the drainage problem.*

* Disposal of Sewage at the Massachusetts Reformatory. By Wm. Wheeler, C.E., 7th An. Rept. of the St. Bd. of Health, Lunacy, and Charity of Mass. Supplement, etc. (1886), pp. 195-208.

CHAPTER XXXII.

BROAD IRRIGATION AT THE RHODE ISLAND STATE INSTITUTIONS.

THE Rhode Island State Institutions, consisting of the House of Correction, State Alms House, State Hospital for the Insane, State Prison, Sockanosset School for Boys, and the Oaklawn School for Girls, are located at Cranston, a short distance west of the city of Providence, in the midst of a tract of about 500 acres of land owned by the State.

In the fall of 1884, the Board of State Charities and Corrections, which has charge of the State Institutions, requested Samuel M. Gray, M. Am. Soc. C.E., of Providence, to suggestan improved method for disposing of the sewage, which previous to that time had been utilized to some extent in irrigation, but without any special order or system. Mr. Gray, after investigation, recommended systematic broad irrigation, and designated a number of areas which were adapted to such use. His preliminary report was presented to the General Assembly of Rhode Island the following spring, and an Act passed appropriating $10,000, and authorizing the Controlling Board to purchase or condemn, if necessary, not exceeding 50 acres of land to be used specially for irrigation. Work was immediately begun on the construction of an experimental irrigation area, for the disposal of the sewage from the House of Correction, Alms House, and Insane Hospital. For this purpose the sewage was collected and carried to a field some 500 feet east from the buildings, where an area of 3.5 acres was prepared. This area, under favorable conditions, was considered sufficient to temporarily dispose of the sewage of the population of the three institutions named, which amounted to about 850 people, and to also serve as an index of what could be accomplished by land purification at this place.

The area selected was of somewhat irregular and uneven surface, with the top soil, ten inches in depth, of fine light loam underlaid by a sandy subsoil and fine gravel, which grows coarser as the depth increases, until at the depth of six feet it is composed of coarse gravel and sand in such proportions as to form a nearly ideal material for the purification of sewage. A plan of the field as prepared is shown by Fig. 74. The surface of the field was first graded to a uniform slope, and the field then underdrained with 3-inch and 4-inch round tile, laid from 5 to 6 feet in depth, in lines about 40 feet apart. The drains

are shown on Fig. 74 by dotted lines, the full lines on the same figure representing the contours, the elevation of which above tide-water are

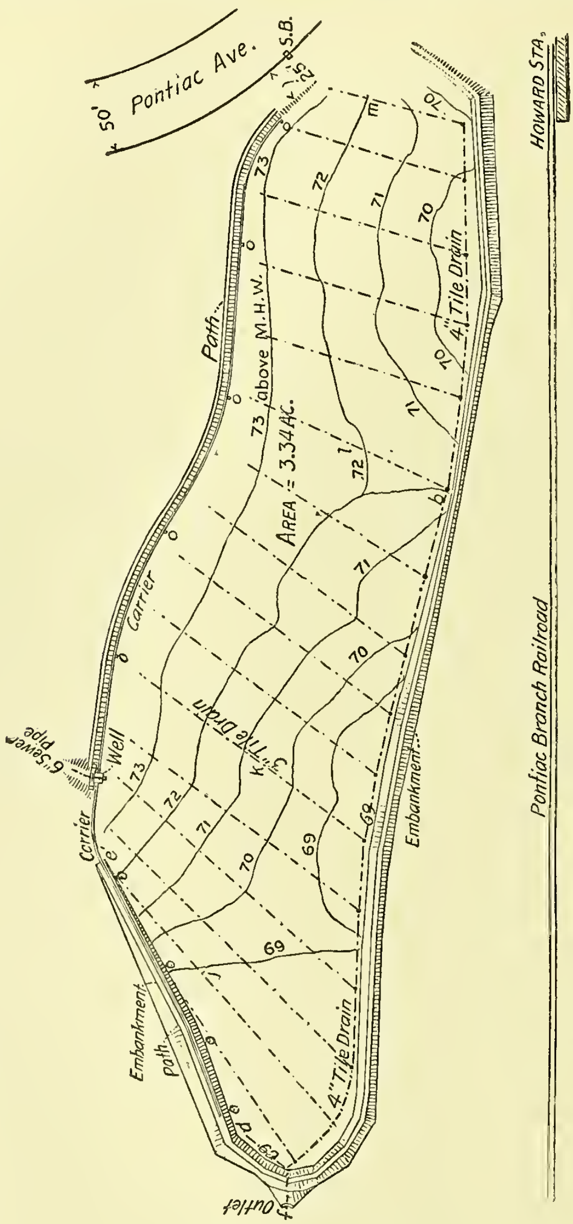


Fig. 74.—Plan of Disposal Area, Rhode Island State Institutions, Cranston.

there given. The 3-inch drains are laid nearly at right angles to the contours, and empty into the 4-inch, which are laid, as indicated, along

the lower side of the field and with a grade of 6 inches to the hundred feet. The outlet of the 4-inch drain is at the point *f*, Fig. 74. At the junction of each line of 3-inch with the 4-inch is a brick well, 8 inches square in the clear, carried above the tiles about 4 inches and covered with brick. The chief object of these wells is to afford means of examining the drains when necessary without breaking the tiles. The method of laying the tiles has been described as follows :

A narrow trench was excavated to a true grade, and in the trench were laid strips of spruce boards, one inch thick and about four inches wide, upon which were placed the tiles end to end and close together, each joint wound with strips of tarred paper about four inches in width, lapping two inches on each tile and extending twice around it. The tiles, as fast as laid, were covered with screened pea-gravel, free from sand, to a depth of about three inches, and this fine gravel was in turn covered with about three inches of coarse gravel, an abundance of this material, coarse and fine, having been obtained from excavations on the field. The trenches were then back-filled, care having been taken to pack the earth solidly. The tile-drains having been completed, the surface of the field was again evened and the soil replaced where it had been previously removed in grading.

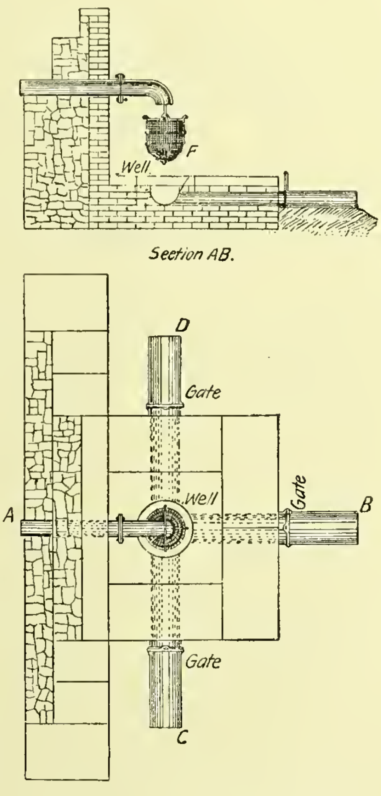


FIG. 75. — SCREENING BASKET, RHODE ISLAND STATE INSTITUTIONS.

In order to form a basin to retain the sewage, if necessary, in winter when the ground is frozen, and also to prevent its possible escape without filtration at any time into the Pawtuxet river near by, from which the water supply of the city of Providence is derived, an embankment was built around the three low sides of the field, as shown in Fig. 74. The following is a description of the works :

The sewage is conveyed to the field in a six-inch Akron pipe and discharged into a wire-basket (at the point *f*, Fig. 74, also shown in the plan and section of the screening well, Fig. 75). The use of the basket is to catch rags or other materials coming from the Institutions through the six-inch pipe, which, if not removed, might interfere with the proper distribution of the sewage upon the field. After passing through the basket the sewage runs into a brick well, and from thence flows in a carrier or trough along the upper or westerly side of the field, from which carrier it is discharged at nine different points by a system of gates, as described further on ; or the sewage may be discharged directly upon the field from the well, as shown at B, Fig. 74.

The carrier was constructed in the following manner (see Fig. 76) : To provide

a foundation which should be affected as little as possible by frost, a trench was dug, three feet wide at the top and two and one-half feet wide at the bottom, having a depth of three feet. This was filled to a point two feet and eight inches from the bottom with loose stone closely packed, the upper layer composed of pieces about one inch in diameter. On this stone foundation concrete was laid about four inches in depth, composed of one part cement and four parts gravel and sand, and upon the top of this the carrier rests. To form properly this concrete bed, boards twelve feet long and nine inches wide were placed nearly upright and in the direction of the carrier, the bottom edges eighteen and the upper edges sixteen inches apart, giving a batter of one inch to each side of the bed. To hold in position the boards thus placed, short strips of wood notched near the extremities were placed across the boards, near the ends and in middle, both above and below, the edges of the board fitting closely into the notches of the strips. A plan and end-view of one set of boards and cross-pieces in position are shown at G and H, Fig. 76.

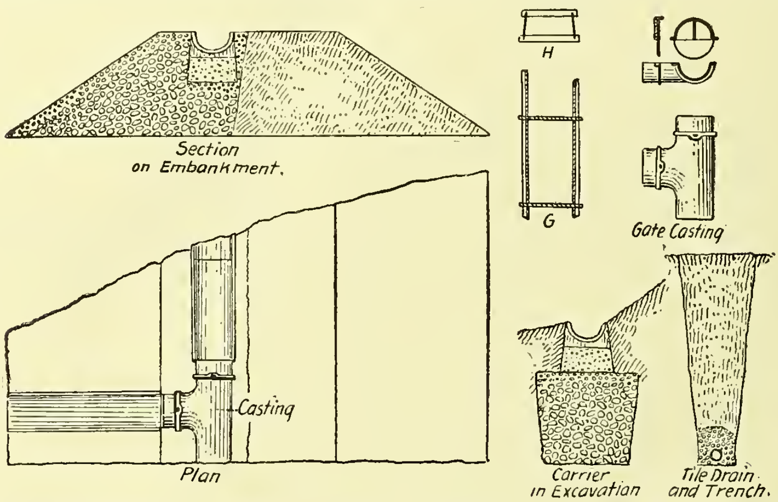


Fig. 76.—Details of Carrier and Drain, Rhode Island State Institutions.

The carrier itself is made of twelve-inch vitrified pipe divided longitudinally in the centre, making what is known as "split pipe." This is done by cutting grooves in the clay while soft before baking, so that when taken from the kiln the pipes are easily divided into two longitudinal sections of equal size.

These half-pipes were placed to line and grade upon the concrete bed so as to form a continuous trough, and backed up with brick and cement. (See section of carrier on Fig. 76.) Along the line of carrier, at distances of about one hundred feet, were placed iron castings, each casting taking the place of a section of the vitified half-pipe, having the same trough-like form, and arranged with a system of gates as before mentioned. These are shown in plan and elevation on Fig. 76, from which a better conception can be formed than from description. By means of these gates the whole or part of the sewage may be discharged upon the field at any of the points where these castings and gates are placed.

The most difficult engineering operation relating to the sewage of the State Institutions, namely, that of disposing of the sewage of the State Prison, was not entered into in 1885, there being no portion of the area already owned by the State upon which the sewage could be delivered by gravity which was considered suitable for broad irrigation, and the alternative of pumping the prison sewage upon suitable areas

of the State land was thought to have so many objectionable features that its adoption was not deemed advisable, unless it should prove impracticable to obtain, by purchase or otherwise, sufficient land so located with reference to the prison as to permit delivering the sewage thereon by gravity. It was to meet this difficulty that the Act authorizing the purchase of additional land was passed. Under its provisions a little over 12 acres were purchased for the sum of $3,959.79.

A definite statement of the cost of the work cannot be given, inasmuch as the manual labor needed for draining, grading, etc., was furnished by the inmates, under the direction of the Superintendent of State Institutions. Aside from such labor there was paid out on account of construction, up to December 31, 1885, the sum of $3,424.12.

The direct supervision of the construction work was intrusted to Joseph A. Latham, C.E., who acted under the direction of Mr. Gray.

In regard to the winter disposal at this place, the following statement was made by Frederick P. Stearns, M. Am. Soc. C.E., in a discussion of sewage disposal before the Boston Society of Civil Engineers on February 15, 1888:

> I visited the sewage disposal area of the State Institutions at Cranston, R. I., on the 28th day of January, 1888. The temperature of the air in the morning was −19.4° C. (3° below zero F.), and at one P.M., at the time of the visit, −15.6° C. (4° F.). This was one of the coldest days of the season, at the end of a very cold week, and near the end of the coldest January since 1857.
>
> The populations of the institutions contributing sewage was about 1,000, and the mean flow about 90,000 gal. per day. The sewage was being turned upon a level tract of about 2.5 acres. The surface of the ground was generally covered with ice about 5 inches thick. Near where the sewage went upon the field it was not frozen. Beyond this it appeared to be flowing over the ice, and a new layer was forming upon the surface of the sewage. To all appearances very little sewage was entering the ground. It is evident, however, either that the sewage did enter the ground or that it had been filtering through prior to this time, as the total accumulation of ice upon the surface did not represent more than 8 days' flow of the sewage, and a large portion of it was probably due to rain and snow, the precipitation for the month having been 4.5 inches. The areas were so arranged that no sewage could run off over the surface.
>
> . . . .
>
> Not only was the weather very cold, but the temperature of the sewage, 4.7° C. (40.5° F.), was unusually low. The average temperature of Medfield sewage in January, 1888, as deduced from daily observations, was 16° C. (60.7° F.). The mean temperature of sewage of the Concord Reformatory during the last week in January was 11.1° C. (51.9° F.). The mean temperature of Boston sewage during this month was 6.3° C. (43.3° F.).

Recent statements in regard to the condition of the purification works at Cranston are lacking, as are also statements as to the actual cost of operation; but the latter item is quite small, since independent of the use of a portion of the sewage for the irrigation of crops it requires considerably less than the time of one man.*

* The chief source of information in regard to the disposal works at Cranston is the 17th An. Rept. of the Bd. Charities and Corrections of R. I. for 1885. Also see Eng. & Bld. Recd., vol. xiii., p. 322 (March 4, 1886).

CHAPTER XXXIII.

INTERMITTENT FILTRATION AND BROAD IRRIGATION AT SOUTH FRAMINGHAM, MASSACHUSETTS.

THE town of Framingham, Massachusetts, of which South Framingham is the principal village, is situated in the drainage area of Lake Cochituate, from which a portion of the water supply of Boston is derived, as is shown by Fig. 77. Until recently the sewage of the town has flowed into Beaver Dam brook, a tributary of Lake Cochituate. In the latter part of the year 1889 complete sewerage and sewage disposal works were completed and put in operation.

A project for the disposal of the sewage of South Framingham was elaborated by Eliot C. Clark, M. Am. Soc. C.E., in his report to the Massachusetts Drainage Commission in 1885.* At that time it was proposed to convey the sewage from the towns of Ashland and Natick and the village of South Framingham, and also from Sherborn prison, to a common point for disposal—a tract of land just outside of the Lake Cochituate drainage area and in the area of the lower Sudbury river basin being selected.for this purpose. Mr. Clark's proposition was to purify the combined sewage of the towns and the prison by intermittent filtration at this point. His plan included the delivery of all the sewage at a pumping station to be located near the Boston and Albany railroad, a little west from the estuary of the Beaver Dam brook, and from that point to be delivered through a force main to the proposed filtration area, about one mile to the north.†

The selectmen of Framingham, in the latter part of 1886, engaged

* As early as 1879, Desmond FitzGerald, M. Am. Soc. C.E., from one of whose reports the map, Fig. 77, was originally taken, began to urge the importance of excluding sewage from the Boston water supply. Further details of this movement on the part of Boston are given in Eng. News, vol. xxix., pp. 98–99 (Aug. 4, 1892).

† By the Public Statutes of Massachusetts, Chapter eighty, Section ninety-six, it is provided:

No sewage, drainage or refuse or polluting matter of such kind and amount as either by itself or in connection with other matter will corrupt or impair the quality of the water of any pond or stream hereinafter referred to, for domestic use, or render it injurious to health, and no human excrement shall be discharged into any pond used as a source of water supply by a city or town, or upon whose banks any filter basin so used is situated within 20 miles above the point where such supply is taken, or into any feeders of such ponds or streams within such 20 miles.

It is therefore questionable whether any town in that State has a right to discharge a purified effluent into any stream, pond, or lake which is either the source of a water supply or tributary to one within 20 miles from the point of discharge. Under the Statute it would appear necessary to show the effluent entirely free from polluting matter, before its discharge would become permissible.

S. C. Heald, M. Am. Soc. C.E., of Boston, to make the necessary surveys and plans for sewerage and sewage disposal works for that town alone, and proceeded to obtain from the Legislature an act authorizing the town to construct and maintain a system of sewage disposal.

In the meantime H. H. Carter, C.E., acting as engineer for the Boston Water Board, had reported in January, 1887, that the best method for disposing of the sewage of South Framingham was by filtration at substantially the location selected by Mr. Clark in 1885.

Mr. Heald, as engineer for the town, submitted his report to the Sewerage Committee in August, 1887. He proposed a separate system of sewers, with disposal at the point previously indicated in the reports of Messrs. Clark and Carter. The sewage would flow by gravity to a point near the east line of the town of Framingham, where a receiving tank and pumping station would be located, from which the sewage was to be forced to a disposal area substantially as proposed in the original report of Mr. Clark in 1885. For the main outfall sewer in Waverly street he proposed a pipe 15 inches in diameter, laid to a grade of 1 foot in 400.

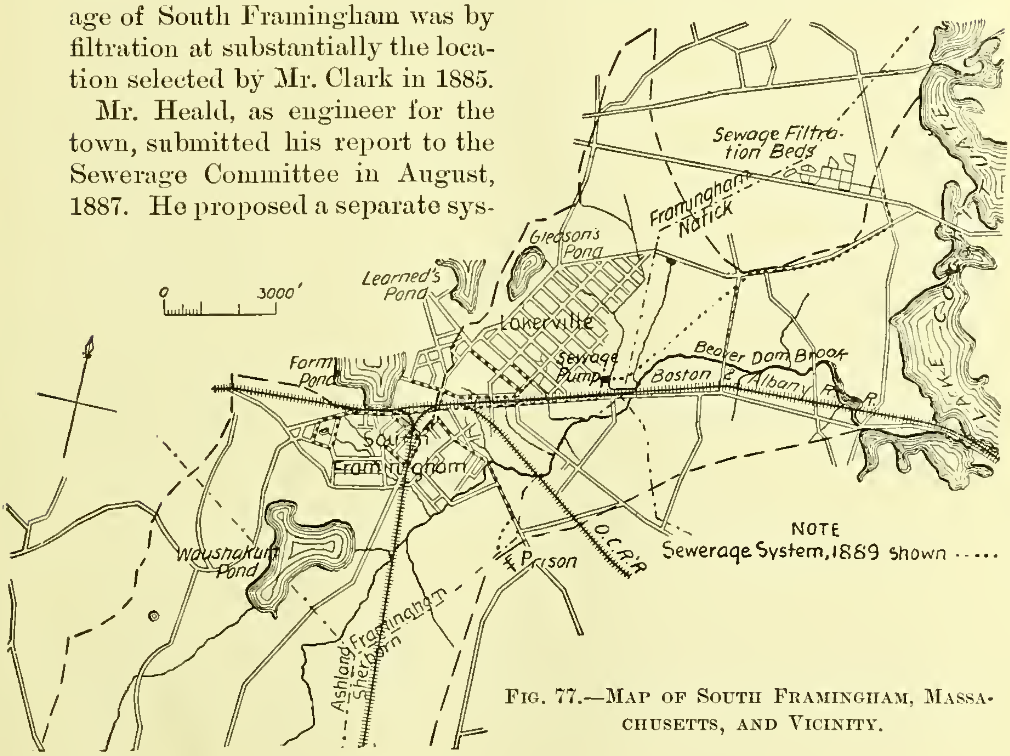


FIG. 77.—MAP OF SOUTH FRAMINGHAM, MASSACHUSETTS, AND VICINITY.

The present population to be provided for is about 5,000, and a volume of about 75 gallons per capita per day was considered a safe basis for estimate.

In regard to the disposal area, Mr. Heald, in his report of 1887, says:

If we avoid the denser clays as altogether unsuitable (unless they are so altered in their condition by mixing, burning, etc., as to lose their natural character), and regulate the application of the sewage to other soils within the limits of one thousand persons to the acre to those most suitably constituted, and two hundred and fifty persons to the acre to those least suitably constituted, all other descriptions of cultivable land may be made capable of filtration.

For the present wants of the town I would advise taking about eighty-five acres of land on the northerly side of the Worcester turnpike and westerly of the road leading from said turnpike to Saxonville. Should the town at any time desire to increase the area of its farm, additional land could be obtained on the northerly side of the brook that crosses the Worcester turnpike near the town line, and land on the easterly side of said road to Saxonville.

The soil is well suited for the purification of sewage, the surface being of light sandy loam and the subsoil for the greater part being coarse gravel.

I have reserved about ten acres of the land for intermittent filtration, the remainder to be used for broad irrigation. The filtration area is to be divided into nine fields, each of which contains nearly an acre of land; each field is to be surrounded by an earth embankment three feet high. These fields are at different elevations, depending upon the natural elevation of the land. Each field is given an elevation that would require the least amount of labor to bring it to a nearly level surface. In preparing a field, after it has been properly graded, a ditch or carrier about two feet wide and one foot deep is formed on one side of the field, and at right angles with the carrier a series of furrows is made. The furrows are from four to five feet apart from centre to centre, and divide the field into long, narrow beds. The beds may be used for raising root crops, the sewage flowing through the carriers and furrows without coming in contact with the vegetables in the beds.

In practice it may be found that the filtration fields are not needed during the summer months—that the area devoted to broad irrigation and the demands for sewage from the owners of land along the line of the force main, even in rainy weather, will be sufficient to dispose of all the sewage.

If such should be the case the fields may be used to take the sewage during the winter months, and in the summer any suitable crop could be raised in them without any especial preparation of the beds.

By having embankments around them, the fields can be flooded to a depth of at least two feet, should occasion require it.

It is impossible to state just how a sewage farm should be conducted in order to attain the best results in respect to crops, or just what crops should be raised; but for the area devoted to broad irrigation a grass crop would undoubtedly be the best. Some of the land to be devoted to the broad irrigation may be ploughed in the autumn and lay fallow, receiving during the winter an occasional dressing of sewage, and in the spring cross-ploughed and a crop of corn or oats started.

The area to be devoted to sewage farming should be thoroughly cleared of all trees and brush. The sewage may then be applied and the land be gradually put into a suitable condition for the growth of grass or other crops.

. . . .

The area of land recommended to be taken will undoubtedly be sufficient to meet the wants of the town for at least fifteen years, and the additional land referred to would be ample for any probable growth of the town.

In advising your town to adopt this method of disposing of its sewage I am not advising anything experimental. In England the same treatment of sewage has been in successful operation for nearly thirty years. On the Continent the following cities, having a winter climate nearly like that of Massachusetts, dispose of their sewage upon the land.

Danzig, in 1871, commenced to dispose of its sewage in this manner. In 1873 Berlin decided to adopt the same method, and was followed in a few years by Breslau, and quite recently by Frankfort.

. . . .

The cost of pumping and caring for the sewage at the farm is estimated at twenty-seven hundred dollars ($2,700) per year.

Mr. Heald's report is accompanied by a report by Phinehas Ball, C.E., of Worcester, in which the plans and arrangements proposed by Mr. Heald are strongly commended.

The Sewerage Committee of the town, having accepted Mr. Heald's report, proceeded to negotiate with the Boston Water Board in order to ascertain how much the city of Boston would contribute toward the expense of the construction of such system of sewerage and of sewage disposal for South Framingham as would result in preventing the flow of any of the sewage of the town into the tributary streams of Lake Cochituate. As the result of the negotiation on the part of the Town Sewerage Committee, the Boston Water Board proposed to contribute twenty-five thousand dollars ($25,000) whenever the town should complete and put in service so much of the system devised by Mr. Heald as provided for the irrigation field, force main, pumping plant, and main trunk line sewer from Bridges street to the pumping station, provided that said work should be completed on or before December 31, 1889.

Upon receipt of this proposition, the Town Sewerage Committee submitted the offer of the Boston Water Board to the Hon. Wm. Gaston for a written opinion as to the validity and the power of the Water Board to bind the city of Boston to such payment.

The following is the opinion received:

BOSTON, February 7, 1888.

TO THE DRAINAGE COMMITTEE
OF THE TOWN OF FRAMINGHAM, MASS.

GENTLEMEN: Referring to the letter addressed to the inhabitants of the town of Framingham by the Boston Water Board, and approved by the Mayor of Boston February 3d, 1888, concerning which our opinion has been asked, we beg leave to say that we have examined the same and are of the opinion as follows:

By the provisions of Chapter 167 of the Acts of the year 1846, entitled an "Act for supplying the City of Boston with pure water," the city is, after an enumeration of various powers, finally authorized at the close of the second section of the Act, to do "any other acts and things necessary or convenient and proper for the purpose of this act;" this same general power was also conferred upon the city by the provisions of Chapter 177 of the Acts of the year 1872, in reference to the supply of pure water to the city of Boston from Sudbury river and Farm pond.

The powers thus given to the city (which in our opinion should be construed liberally) were, under the provisions of Chapter 80 of the Acts of the year 1875, and of an ordinance passed by the City Council, thereunder transferred, so far as they could legally be delegated, to the Boston Water Board. In our judgment the general powers above recited in the Acts of 1846 and 1872 could thus be legally delegated, and are now vested in the Water Board.

That Board has therefore, in our opinion, the power to do any acts and things necessary or convenient and proper for the purpose of supplying pure water to Boston, either from Lake Cochituate or from Sudbury river or Farm pond. There can be no doubt that any system of sewerage which has for its object the removal and discharge of sewage and polluting substances which now naturally drain into the above sources of Boston's water supply, to a point outside the watershed furnishing

such supply, is a proper and convenient thing for accomplishing the purpose of the two acts named, viz., to give Boston pure water. And we are accordingly of opinion that the Boston Water Board has the power to contribute, or agree for the city to contribute, any sum which it deems proper towards the construction of such sewerage system. It can in our judgment make no difference so far as Boston is concerned whether the beneficial work so paid for by Boston is done by persons directly in the employ or by the town of Framingham in its municipal character. In our view the proposed contract, if duly accepted by the town of Framingham, is binding on the city of Boston. Under the provisions of the new city charter (St. 1885, Ch. 266, S. 6), the city of Boston is prohibited from incurring any liability beyond the appropriation duly made therefor. We are informed by the City Auditor that the sum of $50,000 has been duly appropriated by the City Council to be expended by the Water Board for the protection of the purity of the water supply by agreements with the towns of Framingham and Marlborough, and that the sum of money is still on hand. We find upon a recent conference with the Corporation Counsel of Boston that he concurs in the above views.

Yours respectfully,

Gaston & Whitney.

The Committee thereupon recommended the acceptance of the proposition of the Boston Water Board.

In the meantime Mr. Heald's plans had been submitted to the State Board of Health, which, after due consideration, reported, in regard to them as follows:

Office of the State Board of Health,
13 Beacon St., Boston, May 13, 1888.

To the Committee on Sewerage, Framingham, Mass.

Gentlemen: In response to the application from the town of Framingham of March 1, 1888, giving notice of their intention to introduce a system of sewerage and asking advice as to the best practicable method of disposing of their sewage, and approval of the plans presented pursuant to Chapter 403 of the Acts of 1887, the State Board of Health, after fourteen days' notice by publication in the newspapers of Framingham and Natick, and official notice in writing to the Selectmen of the town of Natick of the presentation to it of such system for its approval, gave a public hearing at the State House in Boston on the 24th day of April to all interested in said system, and after careful examination of the plans presented and of the proposed location of grounds for sewage disposal and their surroundings, both by personal examination and by its engineers, this approves of the disposal of sewage of Framingham by irrigation and intermittent filtration upon the tract of land, containing sixty-eight acres, selected by the town, which is located in the town of Natick on the northerly side of the Worcester turnpike and outside of the Boston water supply basin. As the method of disposal of sewage upon this tract is not presented by the town with sufficient clearness to enable this Board to approve or disapprove of the same in detail, the Board therefore approves the system as modified and amended as follows:

The sewage should be applied to so much of the surface of the tract of land as is more than four feet above the level in summer of the water in the brook draining the tract, and at or near this height on the slope towards the brook, and near the lower border of the tract upon which sewage is to be applied, in those sections not sloping directly towards the brook, there shall be constructed an embankment of earth as much as one foot high above the adjacent surface to which sewage is to be applied, and four feet wide, which shall at all times be maintained at such height as to prevent any sewage applied to the surface from flowing over the surface of the ground into the brook or upon adjoining land; and the Board further amends by directing that the top of the underdrains to convey the effluent from the filtration or irrigation areas shall not be less than four feet below the surface of the ground to which sewage is applied; and the Board further amends by directing that the quantity of sewage to be applied to any filter-bed or any irrigation area

shall not exceed in any week the equivalent of one foot in depth over the whole area of that bed or irrigation area to which it is applied, and the times of application shall be so arranged that no liquid sewage shall remain exposed upon the surface or in open ditches more than twenty-four hours at a time. It is understood that the receiving reservoirs are to be completely covered and ventilated by flues extending to the flue of the chimney of the pumping station, and both reservoirs and pumping station are to be located within the town of Framingham. As herein modified and amended the proposed system of sewage disposal and its location are approved.

Per order of the Board,
(Signed) SAMUEL W. ABBOTT,
Secretary of State Board of Health

The preliminary arrangements having been all satisfactorily made, a portion of the work was advertised for letting June 18, 1888. The con-

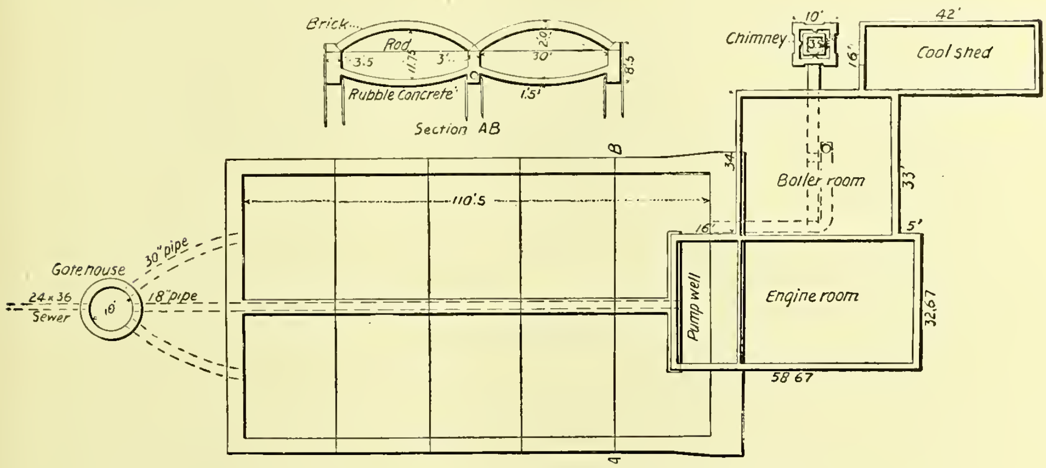


FIG. 78.—PLAN OF RESERVOIRS AND PUMPING STATION, SOUTH FRAMINGHAM, MASSACHUSETTS.

struction began immediately thereafter and proceeded as rapidly as possible. The work was practically completed about November 1, 1889. The following extracts from the report of J. J. Van Valkenburgh, engineer in charge of construction, give the main facts in regard to that portion of the work which relates more particularly to the sewage disposal.

The two receiving reservoirs at the pumping station are each one hundred ten and a half feet long and thirty feet wide. [See Fig. 78 for plan of reservoirs and pumping station.] These are parallel to and separated from each other by a wall three feet thick and seven and one-half feet high. The side walls are three and one-half feet thick and eight and one-half feet high. The brick arches, two feet in thickness, rest on these walls.

The bottoms of the reservoirs are inverted and are constructed of rubble concrete, varying in thickness from one and one-half feet in the centre to two feet at the walls. In the centre of the reservoirs the arches are eleven feet and nine inches

above the invert, and at the walls three and one-half feet. The reservoirs when completely filled will hold four hundred and thirty-one thousand gallons.

. . . .

Both of the reservoirs may be kept free of sewage while the pumps continue to run, being fed by means of an eighteen-inch pipe extending through the centre wall from the gate house to the pump-well.

The pump-well and gate house are both arranged for screens, but it is hardly probable that it will be necessary to resort to screening the sewage, since the pump valves are of the swinging type, eight by ten inches in diameter.*

. . . .

The pumping station and chimney in every particular are of ample size to accommodate a duplicate set of machinery similar to what you now have. The pumping engine is one of M. T. Davidson's improved compound duplex condensing type, and is guaranteed to deliver, through nine thousand feet of twelve-inch pipe, two million U. S. gallons of sewage per twenty-four hours, against a total head of forty feet. This total head does not include friction. This then is at the rate of thirteen hundred and eighty-nine gallons per minute, or eighty-three thousand three hundred and thirty-three gallons per hour. Thus if the reservoirs were completely filled, pumping at the rated capacity of the pumps, they could be emptied in five hours and ten minutes.

Water for the boilers and condenser is taken from a well, six feet in diameter and twelve feet deep, situated near the brook which flows by the easterly side of the station. This well is connected with the brook by an eight-inch pipe. The depth of the well is such that in case said stream becomes too low to be of service, the drain in Waverly street or Beaver Dam brook can be piped so as to flow into the well.

. . . .

There are two steel boilers of the horizontal tubular type, each forty-eight inches in diameter, thirteen feet and two inches long, and containing fifty-two three-inch steel tubes twelve feet long.

The shell of the boilers is three-sixteenths of an inch thick; the heads three-eighths of an inch.

A three-foot flue extending from the reservoirs passes under and in front of the boilers, and is then connected by a two-foot pipe with the thirty-inch flue leading from the boilers to the chimney.

The draught for the boilers is taken from this source. You see, therefore, that the reservoirs have an excellent ventilation.

The twelve-inch cast-iron force main, which is ninety-seven hundred and forty feet long, extends in nearly a straight line to a point on Hartford street about four hundred and fifty feet east of Bowdoin lane. Thence following the southerly side of said street and the easterly side of Speen street (or road to Saxonville), it reaches the farm at a point three hundred feet north from the Worcester turnpike; thence in a straight line and parallel with said turnpike one hundred and eighty feet to the first manhole, where the force main ends; but the same course is continued two thousand feet further with fifteen-, twelve-, and ten-inch Akron pipe laid to a grade of one foot in a thousand.

The force main is laid to grade; that is, by opening a six-inch gate in the engine room, six thousand one hundred feet of this main will drain into the reservoirs. Through two more gates of the same size the remainder of the pipe can be emptied. The advantages of this arrangement will be better appreciated when it becomes necessary to repair a possible break or leak.

Eleven six-inch plugged branches have been put in on line of the force main at such places as seemed to us most advantageous to those who might desire to take the sewage as a fertilizer.

On lines of pipe at the farm there are fourteen hexagonal man-holes, so constructed that when the pumps are working, by closing a gate on the pipe extending through them, the sewage will rise in them. At certain distances up the sides of the manholes there are eight-inch gates, generally four of them, at elevations one

* Near the beginning of 1892 screens were added to remove some of the coarse matters.

foot higher than the bed or point of land upon which it is desired to let sewage flow. Regulating the opening of these gates regulates the amount of sewage delivered.

The farm, containing sixty-nine acres, three roods, and eleven and one-tenth rods, is now in good shape to receive its first instalment of sewage. All wood, excepting that reserved by the town, has been cut, likewise this season's growth of sprouts. About twelve acres of land have been taken for intermittent filtration; the remainder is to be devoted to broad irrigation. The area for intermittent filtration has been divided into eleven beds, with banks about three feet high and four feet broad at the top, with sides sloping one and a half to one. One embankment, through which extends the main feed pipe, is somewhat higher in certain sections than the others, in consequence of giving said pipe the same depth of covering. In preparing a bed a portion of land was taken which was as generally level as possible, and after ploughing, grubbing, and removing as much loam as was necessary to form the embankments, to smooth off the surface and replough into lands seven feet in width. The ditches produced by thus ploughing are about nine inches deep and twice that in width. These ditches are met at the banks by a larger ditch or carrier, which will conduct the sewage from the manholes into them. Eight of the beds are finished, and their embankments in proper shape and seeded. The remaining three beds are graded, and the loam has been put on line of embankments as disposed of by the carts. Two beds have been ploughed with a swivel plough from one side, consequently these beds do not have a series of ditches similar to those possessed by the beds just described. But they have a main carrier along the upper sides, from which the sewage will flow into the furrows as ploughed.

Six of the beds have a six-inch underdrain, six feet below the surface of the ground. These drains extend through nearly the centre of the beds, and their outlets are in the ravines near the centre of the farm. During the most rainy season no water has been observed to come from them, excepting the case of one drain that is in close proximity to the bed of the pond that formerly existed near the Worcester turnpike. The point of observation of this drain is outside of the beds and eight feet below their general level. We think it advisable, therefore, to defer further underdraining until the assured necessities of the beds demand it.

We also advise devoting as much of the sewage as is practicable to broad irrigation, reserving the beds as much as possible.

According to the financial statement submitted by the town's sewerage committee at the completion of the work, the total cost of the sewerage and sewage disposal works was $148,288. The statement does not show the amount properly chargeable to sewage disposal, but an idea of the cost of the same can be derived from Mr. Heald's original estimate, which stood as follows:

26,088 lin. feet of sewer, all sizes, with man-holes	$63,756 50
Pumps and boilers in duplicate	8,000 00
Chimney, engine and boilers house	7,000 00
Foundations, screens, gates, etc	3,000 00
Receiving reservoirs (250,000 gallons capacity)	12,000 00
10,200 lin. feet of 12-inch force main, at $1.85	18,870 00
85 acres of land at $40	3,400 00
Clearing and burning 65 acres, at $20.00	1,300 00
Filtration beds and carriers	10,000 00
Amount	$127,326 50
Add 10 per cent. for engineering and contingencies	12,732 65
Total estimated cost	$140,059 15

In regard to the increase in cost of the work in actual construction over the amount of the estimate, it is stated by Mr. Van Valkenburgh

in his report, from which we have already quoted, that the increase was due to the large number of heavy storms which occurred while the work was constructing, necessitating extra pumping, additional underdrains, deeper foundations and more extended supervision, etc. In order to facilitate construction, 8,058.4 lineal feet of underdrain were constructed which were not contemplated in the original estimate.

Mr. Baker visited South Framingham on June 17, 1892, and through the kindness of Mr. Van Valkenburgh, obtained some additional information. John H. Goodell, chairman of the Framingham Sewerage Committee has since added to this information, as has Frederick P. Stearns, chief engineer of the Massachusetts State Board of Health.*

To June, 1892, none of the farmers along the line of the outfall sewer had availed themselves of the opportunity to draw sewage from it through the eleven 6-inch branches provided for this purpose.

In 1892 corn was successfully raised on three of the beds.

The following table gives an analysis, furnished by Mr. Stearns, of the sewage, effluent, and unpolluted ground-water at South Framingham.

ANALYSES OF SEWAGE, SEWAGE EFFLUENT, AND UNPOLLUTED GROUND WATER FROM THE SEWAGE FIELD AT SOUTH FRAMINGHAM, MASSACHUSETTS.

(Parts in 100,000.)

	Color.	Total residue on evaporation.	Ammonia.		Chlorine.	Nitrogen as	
			Free.	Albuminoid.		Nitrates.	Nitrites.
Sewage	0.70	28.30	1.7893	.3750	4.07	.0080	.0001
Sewage effluent at underdrains	0.00	19.45	.0335	.0039	2.56	.6018	.0006
Sewage effluent at spring	0.00	7.23	.0000	.0029	1.77	.2350	.0000
Unpolluted ground water	0.00	4.70	.0000	.0008	0.20	.0083	.0000

Mr. Stearns comments upon these figures and the work of the disposal area as follows:

In each case the analyses are the averages of several determinations. They represent, first, the sewage as it flows out of the carrier upon the beds; second, the effluent flowing from underdrains beneath certain of the beds, which afterward soaks into the ground and is filtered the second time before reaching the brook into which the effluent finally passes; third, the water of a spring located near the brook, which derives its supply to a large extent from the sewage effluent, and represents the general character of the effluent when it reaches the brook; and, fourth, the unpolluted water from a flowing well near by.

Only a small part of the sewage effluent comes out at the underdrains, and you will notice that this is purified to such an extent that there is only 2% of free ammonia and 1% of albuminoid ammonia remaining, while the nitrates have increased greatly. At the spring the free ammonia is entirely removed and the albuminoid

* See Eng. News, vol. xxviii., pp. 127–9 (Aug. 11, 1892).

ammonia is less than one per cent. of that in the sewage. On one occasion an analysis of the spring water showed that it contained neither free nor albuminoid ammonia, while the excess of chlorine and nitrates over the amount found in the unpolluted ground-water, as shown in the last line, proves without doubt that this spring contains a large proportion of sewage effluent.

Bacterial examinations of the sewage and of effluent collected from the spring show that nearly, if not all, bacteria are removed by filtration.

The effluent from this sewage field flows into a small brook, and although the works have been in operation more than two years the discharge of the effluent into this brook has not produced any noticeable effect.

In the report of the Sewer Committee for March, 1893, it is stated that there were then 451 houses and 39 hotels and business blocks connected with the sewers—222 new connections, or nearly one-half the total, having been made in the year 1892–3. At the sewage farm it is stated that 400 bushels of corn (probably in the ear), three-fourths of an acre of cabbages, and some squashes were raised in 1892, and sold for a total of $174.

The effect of frost and snow upon these filter beds is given in Chapter XIV., page 284.*

* The chief source of information in regard to the South Framingham sewage disposal is Reports of the Committee on Drainage and Sewerage and Construction of the Sewerage System, etc., Nov., 1889. Compiled by Wm. A. Brown, Clerk to Selectmen. Also see Eng. News, vol. xxii., p. 497 (Nov. 23, 1889); vol. xxviii., pp. 127–9 (Aug. 11, 1892).

CHAPTER XXXIV.

INTERMITTENT FILTRATION AT MEDFIELD, MASSACHUSETTS.

In the fall of 1886 sewerage and sewage disposal works were constructed at Medfield, Massachusetts, a small town on the Charles river, about 17 miles from Boston. The sewage disposal works, which include preliminary sedimentation and upward filtration through excelsior, supplemented by intermittent filtration through natural soil, were projected by Eliot C. Clarke, M. Am. Soc. C.E., and constructed under the supervision of Fred. Brooks, M. Am. Soc. C.E. The plans for the sewage disposal works were approved by the Massachusetts State Board of Health in August, 1886.

The chief manufacturing enterprise at Medfield is the Excelsior Straw Works, which employ for seven months of the year between six and seven hundred operatives, and during the remainder of the year about half as many.

The following account of the Works is extracted and condensed from a paper by Mr. Brooks, Sewage Disposal at Medfield, Massachusetts, in the 19th Annual Report of the Massachusetts State Board of Health:

The straw-works drainage, nearly half of which comes from the vats in which straw is dyed, used to run into Vine brook, which flows past the works and is dammed up in a small pond just below, whose level is frequently raised and lowered for mechanical purposes. This produced an offensive smell around the pond, and blackened and polluted the water so that some residents below, on both sides of the brook immediately west of the railroad track, who had used its water for domestic supply, were obliged to abandon it, and made several complaints. In 1886 a pipe sewer was built chiefly for the purpose of keeping the sewage from the straw-works out of Vine brook, and disposing of it so as to avoid the nuisance. The sewer has been entered also by the Central House (having accommodations for about forty boarders), which formerly drained into the brook, and by three private dwelling-houses which did not drain into the brook. As a result the channel of the brook has already been washed so that it is inoffensive to sight and smell. A favorable place was found a little out of the village for the discharge of the sewage and its purification by intermittent downward filtration.

. . . .

Much ground dye-wood is used at the straw-works, and if this in its water-logged condition were admitted to the sewer it was not to be supposed that the sewer would be self-cleansing with the gradient available. It falls at the rate of 4 per 1,000 for nearly a quarter of a mile. Accordingly to exclude the spent dye-wood from the sewer there was built adjacent to the dye-house a settling basin with a filter, whose construction may be understood by the aid of the accompanying drawing [Fig. 79]. It is made in two parts, side by side, exactly alike, in order that one-half may be in use, if necessary, while the other is being cleaned out. The discharge from the vats can be turned, by a wooden gate in the trough which brings it

from the dye-house, into either side of the settling basin separately. Entering by the four-inch openings the liquid flows generally in both sides, with a total width of ten feet and a depth of four feet, less the thickness of the deposit of sediment. The velocity of flow is thus checked, and the ground dye-wood has a chance to settle. To get into the second pair of compartments it has to pass over the brick dividing wall, whose elevation is the same as the bottom of the inlet pipe. Here is another opportunity for settlement to take place, but apparently very little collects in the second compartments until the first are pretty well filled. In the third compartments by a tight board partition the liquid is obliged to pass downward, and escape by upward filtration through a mass of excelsior held between two sets of wooden slats, as exhibited by the drawing; the upward flow being preferred as a precaution against choking the filter. The filter was in use nearly a year before the excelsior was changed; it worked very satisfactorily, but the excelsior had by that time become so rotted that probably it would soon after have gone to pieces and escaped through the sewer. A new supply was accordingly substituted. The sediment needs to be shovelled out and carted off once or twice a year; it has a similar appearance to saw-dust, except for its black color.

. . . .

Near the lower end of the sewer the sewage passes through a cesspool arranged as shown on the accompanying drawing [Fig. 80], so that the outflow takes place from beneath the surface of the sewage standing in the cesspool. The effect is that objects which either float or sink are held back until they are sufficiently changed by chemical or other action to flow uniformly with the rest of the liquid, and are prevented from being thrown out upon the ground at the outlet. . . . Very little sediment collects in the cesspool—only about a foot in depth in the course of a year; when it fills up, the sediment will have to be taken out.

. . . The filtering bed upon which the sewage is discharged consists of one acre of ground graded nearly level. It was intended to be conical, sloping at the rate of five per thousand away from the centre, where the outlet of the sewer is; but owing to slight imperfections in the work, unequal settlement, etc., it is a little irregular—generally flatter. . . . The shape of the filtering bed was made a little irregular to adapt it to the existing topographical conditions; but it is substantially a square, subdivided into four small squares of one-quarter acre each by little embankments, three of which are about a foot in height; the fourth covers the pipe to a depth of three feet for protection against freezing or other injury. To prevent the sewage from running off from the filtering bed without penetrating its surface, the filling was also embanked about a foot above the graded surface along the north-east side of the filtering bed, the only portion of the exterior line where the graded surface was not lower than the ground adjacent. The material is mostly gravel and stones from the size of a man's fist downward, and is well suited for the purpose of filtration. In grading the filtering bed the thin stratum of loam and grass upon the surface was not removed; it was simply ploughed up and then handled like the gravel. But the narrow strip under the embankment through which the pipe is laid had its loam stripped off, and the gravel with which it was replaced was carefully puddled to make an unyielding foundation for the pipe. At the middle of the filtering bed the pipe sewer ends [as shown by Fig. 80] in a wooden

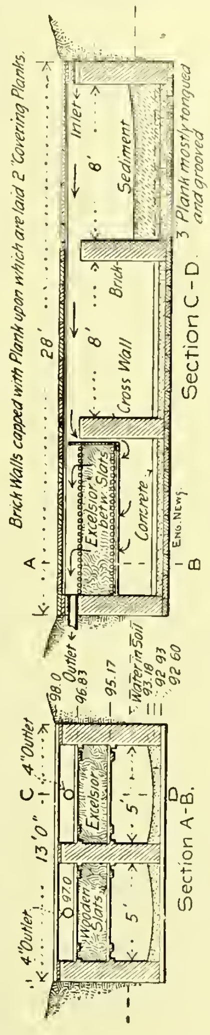


FIG. 79.—SECTIONS THROUGH SETTLING AND FILTERING TANKS, MEDFIELD, MASSACHUSETTS.

trough having four outlets—one to each subdivision of the filtering bed—which outlets are closed by three gates; so that the sewage runs on to one subdivision, and is shut off from the other three. Every other day the gate is changed from one outlet to the next, so as to turn two days' sewage on to a subdivision, and then give it six days' rest, to allow the sewage to pass off through the ground, and let the surface of that division become dry enough for another dose.

No underdrainage has been put in at the filtering bed. The ground-water naturally is about ten feet below the surface of the filtering bed. Judging from the visible indications, especially the contour of the surface of the ground, the natural drainage from the filtering bed must be in the direction of a little depression leading down toward the meadow to the northward, where there is a spring of very good water which is the source of a permanent stream, as shown on the plan and profile. The artificially straight course of the little stream may be explained by the fact that the meadow through which it flows was graded up several years ago, so that better crops could be cultivated. This stream being a tributary of the Charles river, upon whose banks a long distance below are situated

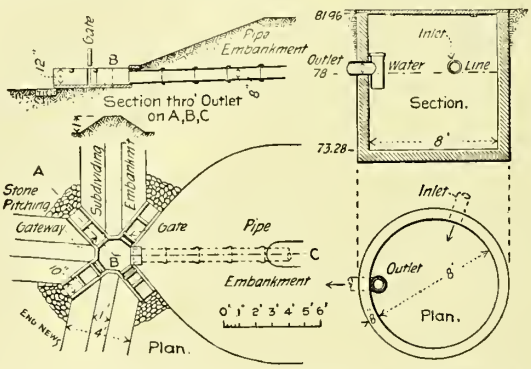


Fig. 80.—Plan and Section through Sewage Outlets and Cesspool.

the filtering galleries from which several municipalities draw their water supply, Medfield sewage requires to be purified before entering it.

. . . .

The success of this filtering bed during the severe cold of winter has been favored by the fact that the dye-vats are kept at a high temperature. Daily observations in October, November, December, and January, 1887–88, show that the temperature of the sewage as it comes upon the filtering bed at the outlet is, while business is active at the straw-works, generally from 60° to 80° F., falling at night and on holidays from that downward to about the temperature of the ground-water, say 50° F. . . . In January, 1887, on a day when the thermometer went down to 26° below zero F., the sewage was turned on to a division of the filtering bed that was covered with snow and ice. The writer visited it a few days later and found that from a strip five or ten feet wide, extending nearly across the bed, the snow and ice had been melted away. The sewage had also run underneath the remaining snow and ice a little way, so that on digging with a shovel through it —say ten feet from this open place—moist and unfrozen ground was found beneath; still further away the ground was frozen.

With regard to the quantity of liquid discharged upon the filtering bed, it was estimated in the latter part of 1887 by putting a little weir at one of the wooden trough outlets and observing at intervals the height of water going over it. It fluctuates a great deal, but it is estimated that in addition to the leakage of 2,000 cubic feet per twenty-four hours of clean water above mentioned, there comes in on the average, from straw-works and the house drains, about 3,000 cubic feet per day for six days in the week for about seven months, from November to May—that

is, about half the days in the year—but only about 1,500 cubic feet per day for five months, from June to October, and on Sundays in the other seven months, *i.e.*, the other of the year. That this estimate (though not claiming to be minutely accurate) is substantially correct may be judged by comparing such estimates as can be made from known facts as to the number of people in the buildings and the quantities usually discharged from the dye-house and bleachery; also by comparing the estimated quantity of water pumped from an artesian well which is the original source of most of the liquid that gets into the sewer. Most of what is pumped from this well ultimately finds its way into the sewer. More has been pumped heretofore than the required water supply, and the excess has been allowed to overflow from a tank and escape into the sewer, making just so much unnecessary hindrance to the drying of the filtering bed; whereas, if pumped at all, it might better have overflowed into Vine brook, being pure water. For purposes of comparison the quantity of liquid discharged upon this filtering bed of one acre (or 4,000 square metres) may be estimated at 4,250 cubic feet (or 120 cubic metres, or 32,000 United States gallons) per twenty-four hours the year round, though the actual want of uniformity must make the effect rather different. For the purpose of comparison as to the population provided for, we may assume, as an approximation, that the manufacturing waste from the straw-works takes the place of the domestic waste that would ordinarily go with the number of operatives that board outside of the sewered area; and thus counting operatives and residents alike, may call the average population provided for about 500.

The works were designed for about 3,000 to 3,500 cubic feet of sewage per twenty-four hours; but the town secured an additional acre of ground around the present graded filtering bed with a view to extending its area, if an increase in the quantity of sewage to be disposed of should hereafter make it necessary. At present the full area prepared is not fairly availed of, because from the neglect to grade the surface more accurately by a little harrowing there are portions which stand high and dry, and have never been touched by the sewage, which collects in the low places where, after two days' discharge, it stands in a pool. The six days following hardly give sufficient opportunity for it to percolate through the soil and for the surface of the filtering bed to become dry. The natural tendency is toward the formation of a moist, pasty coating over the surface of the lowest points of the filtering bed, entirely contrary to the intention with which it was laid out. In spite of this imperfection, which it is not to be supposed will be allowed to continue, the general working of the scheme has been highly satisfactory. No smell is noticeable except just at the outlet of the sewer.

The work for the town was done under a contract for a "lump" sum; the cost of the disposal works was probably about $1,000, including cesspool, pipe from cesspool to outlet, earthwork, engineering, superintendence and profit to contractor, and the value of land, which was given to the town. The annual expense of maintenance of the work of disposal is insignificant—probably about thirty dollars. A man has to change the gate regularly, which is the principal labor required. The surface ought to be harrowed over when it gets clogged with sediment, the embankments repaired if they get trodden down or washed; the wooden parts will have to be occasionally renewed as they decay, the cesspool will have to be emptied sometimes; but a very few days' labor annually will cover all that appears to be required.

No statements as to recent cost of operation have been made.*

* Mr. Brooks's paper gives a series of analyses of (1) the water of wells in the vicinity of the filter area; (2) of a spring near by, below the filter area, which contains some of the effluent; and (3) of the crude sewage; together with the results of a few determinations of bacteria by plate cultures. A record of the temperature of the sewage for the month of December, 1887, is included.

Mr. Brooks's paper, in a slightly modified form, may also be found in the Jour. of the Assoc. of Eng. Socs., vol. vii., No. 7, pp. 235-244 (July, 1888). Also see Eng. and Bld. Recd., vol. xviii., pp. 27-30 (1888).

CHAPTER XXXV.

INTERMITTENT FILTRATION AND BROAD IRRIGATION AT THE LONDON, ONTARIO, HOSPITAL FOR THE INSANE.

THE sewage disposal system at the London (Ontario) Insane Hospital is so interesting that a short description of it is included in this volume, although it is not in the United States.

Previous to 1889 the sewage from the hospital was delivered into a small brook, tributary to the South branch of the Thames river, which flows through the city of London. This brook has only a small drainage area, and frequently becomes nearly dry during the summer season. The population of the hospital is over 1,000 and the daily amount of sewage about 60,000 gallons. The necessity, therefore, for some means of disposal other than into the brook had been for a number of years very apparent.

In 1888 Col. Geo. E. Waring, Jr., M. Inst. C.E., was requested to examine the whole question of sewage disposal, and report plans and such information as would be necessary for carrying out the work advised.

As soon as possible after receiving this commission, Col. Waring reported a project, which was immediately carried out, substantially as follows:

The original system of sewers, which received storm and roof water, was left intact, and a new system of small vitrified pipes laid, connecting with all fixtures throughout the buildings, and flushed by automatic flush-tanks located at the heads of the several lines. The new sewers all deliver into an underground tank, of a capacity of 100,000 gallons, near the main hospital building. The sewage is delivered from the sewers into a screen chamber at one end of the tank, and passes through a vertical screen into the tank proper. Ventilation of the tank is secured by means of six man-holes, three at one end having perforated covers, and three at the other end connected by ten-inch pipes, laid underground, with the chimney of the pump-house.

The disposal area (Fig. 81), amounting to 30 acres, is so situated with reference to the hospital buildings as to render delivery of the sewage thereto by gravity impossible, and accordingly a pumping station was erected about 30 feet east of the tank, containing an eight-inch Webber centrifugal pump, driven by a 25 horse-power Westing-

house automatic engine. The suction is a ten-inch iron pipe, dipping into a small sump in the bottom of the tank at the lower end in such manner as to admit, when necessary, of the sewage being entirely pumped out. This pump has a capacity of about 60,000 gallons per hour; hence, for the present, about one hour's pumping per day will be all that is required. The discharge-pipe is an eight-inch spiral riveted pipe 1,526 feet long, which enters the bottom of a brick distributing well, 4 feet in diameter, at the disposal field.

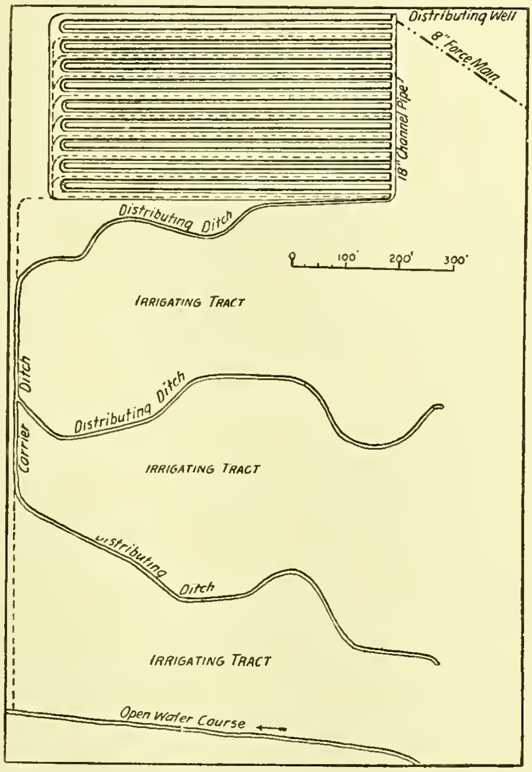


FIG. 81.—DISPOSAL AREA, HOSPITAL FOR THE INSANE, LONDON, ONTARIO.

The method of disposal is intermittent filtration supplemented by broad irrigation. For this purpose an area of about five acres, at the highest portion of the disposal field, has been levelled and laid out in absorption ditches after the manner shown in the cross-section, Fig. 82. The balance of the field, consisting of about 12 acres, is provided with a main carrier and distribution ditches for use as an irrigation area whenever the filtration area is overworked, or whenever during the growing season the sewage can be profitably utilized thereon for growing crops. The intermittent filtration area is divided into three

parts, into one of which the sewage is run for one day, this arrangement giving two days' rest for a section after each application.

The construction was begun in October, 1888, and completed in June, 1889, the work being done by the Department of Public Works

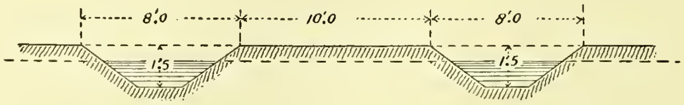


Fig. 82.—Section of Absorption Ditches.

of Ontario, under the general direction of the Architect-in-Chief of the Department. F. W. Farquhar, C.E., of the firm of Waring, Chapman & Farquhar, Civil Engineers, of Newport, Rhode Island, acted as resident engineer.

The entire cost of the work was in the neighborhood of $15,000, the principal items of construction being as follows:

1 sewage collecting tank.
1 pump-house containing boiler, pump, and engine.
1,526 feet spiral riveted force-main.
3,865 feet 6-inch sewers.
640 feet 4-inch sewers.
2 automatic flush-tanks.
1 distributing-well.
320 feet 18-inch channel pipe.
2,700 feet 3-inch tile underdrains.
2,700 feet 4-inch tile underdrains.
1,250 feet 6-inch tile underdrains.
3,000 cubic yards grading.
10,800 feet settling ditches.
2,700 feet irrigating ditches.

The following extracts from Col. Waring's report to the Department of Public Works indicate a number of interesting details, which have been mostly omitted in the foregoing general account.

The plan sent . . . shows . . . the new drains recommended for the collection and removal of foul wastes. These all lead to an underground tank, to be constructed . . . to the rear of the west wing of the main building.

The details of this tank are shown in the drawings. (See Fig. 83.) Its interior size is 70 feet by 40 feet; walls 16 inches thick, with bottom of concrete. It is covered by three longitudinal arches, 12.66 feet span, 12 inches thick, which rest on two longitudinal walls with arched openings. The floor of the tank is graded, varying between elevation 31.9 and 32.3 respectively. Each section has a longitudinal drainage gutter, with its upper end at 32.22 and its lower end at 31.98, 31.94, 31.90, with a cross gutter leading to a sump four feet in diameter with its bottom at grade 30.0.

The bottom of this sump is hemispherical, and the suction pipe of the pump is centrally located, having six inches space between its mouth and the bottom. This mouth should be bell-shaped, not straight as shown in the drawing. The elevation of the ground at this point is 47.5, making the surface of the floor of the tank about 15 feet below the surface.

There are three man-holes at each end of the tank, with covers at the surface of the ground. At the receiving end of the tank, at the head of the central chamber, is a screening chamber reaching to the surface of the ground and with its bottom at elevation 34.4.

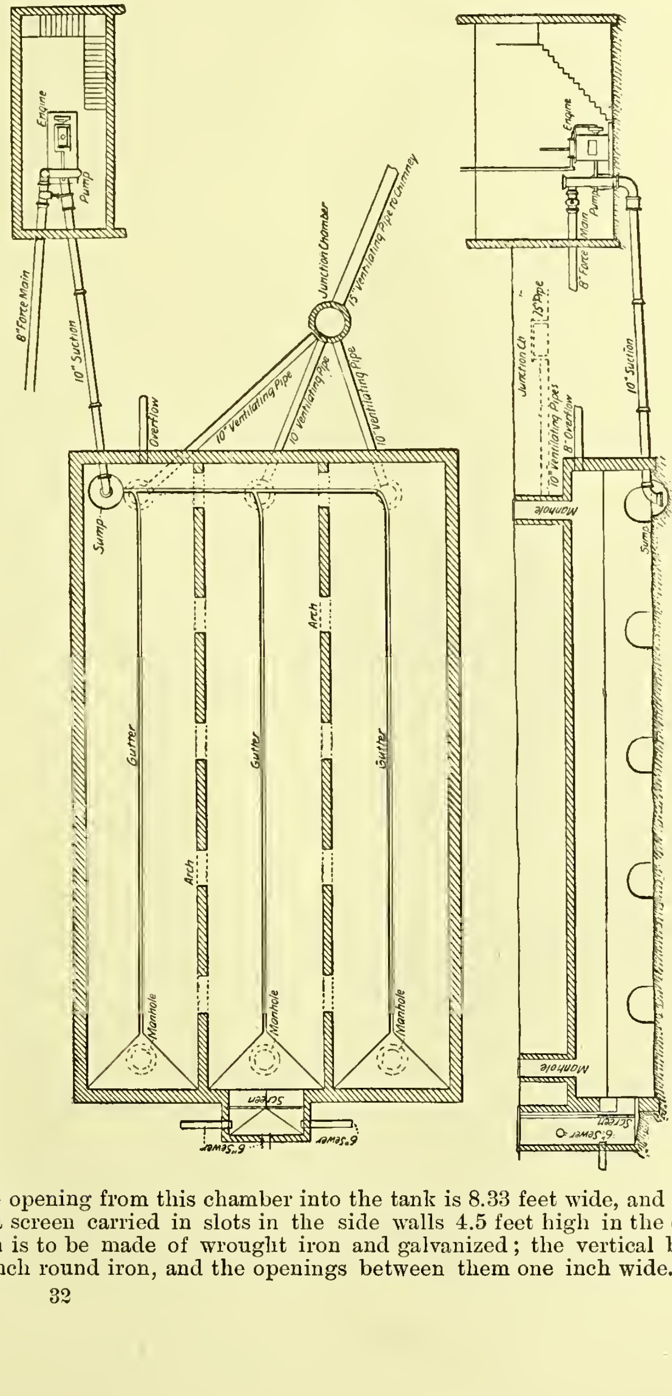


FIG. 83.—COLLECTING TANK AND PUMPING STATION, HOSPITAL FOR THE INSANE, LONDON, ONTARIO.

The opening from this chamber into the tank is 8.33 feet wide, and it is provided with a screen carried in slots in the side walls 4.5 feet high in the centre. This screen is to be made of wrought iron and galvanized; the vertical bars to be of half-inch round iron, and the openings between them one inch wide. The top of

this screening chamber is covered at the surface of the ground with a hinged wooden cover.

. . . .

The receiving well . . . is to be constructed as shown in the drawings. Its inlet is at the bottom, and the force main has a continuous rise from the pump. The pump has no valve. Therefore, whenever the pump is stopped the contents of the receiving well and force main will flow back into the tank, so that there will be no trouble from freezing.

At the highest part of the field a tract . . . is brought to an absolute level at an elevation of about 45.8.

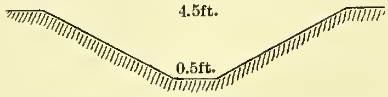


Fig. 84.—Section of Carrier Ditches.

This level tract is laid off in communicating parallel ditches . . . and is underdrained. . . . the main outlet from the receiving [distributing] well has a fall of one in 500. At its lower end it delivers into a distributing ditch, which is continued by a carrier parallel with the west side of the field, from which carrier two distributing ditches are laid as shown. (See Figs. 84 and 86 for sections of carrier and distributing ditches.)

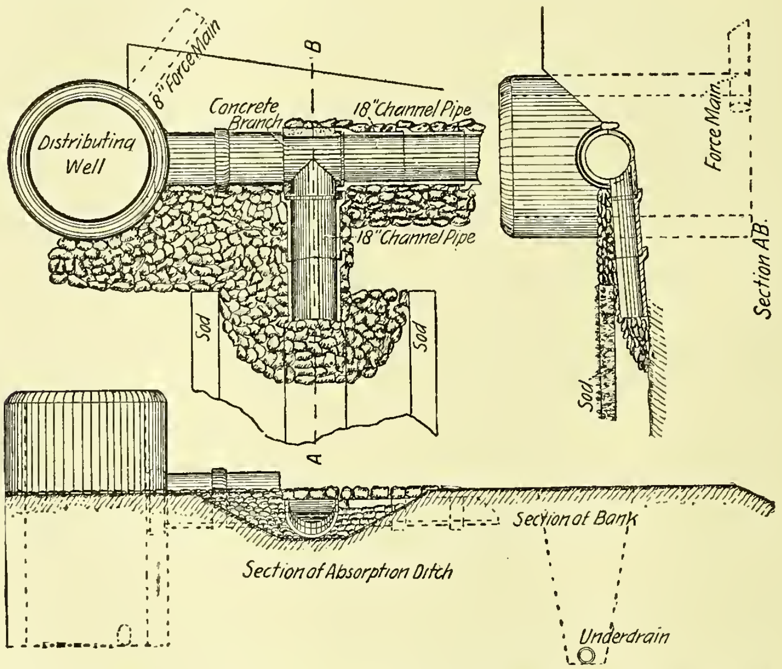


Fig. 85.—Details of Distributing Well, Hospital for the Insane, London, Ontario.

The carrier ditch has the natural fall of the land; the distributing ditches have a fall of one in 500. At a point southeast from the level field there is a short level catch ditch, intended to intercept the surface flow of sewage down the steep slope

near it, and distribute more evenly over the depression below. The need for the catch ditch may be avoided by such grading at this part of the tract as will bring the contours more nearly parallel. . . .

The main outlet from the receiving well is to be made of half pipes (vitrified). This pipe is to be without sockets, and is to be laid in vitrified collars or sleeves.

. . . .

If the flow through the distributing ditch is arrested at any point, as it may be by sticking a wrought-iron gate into the earth, making a dam across the top, the sewage will overflow for a greater or less distance above the dam according to the volume of the current. If the dam is placed first at the lower end of the upper distributing ditch it will overflow, for example, 200 feet above the dam. When the ground to be reached by this overflow has received a sufficient supply of sewage

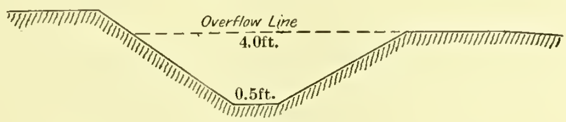


Fig. 86.—Section of Distributing Ditches.

the dam is placed higher up stream, and the overflow carried over the next section of 200 feet, and then in like manner to the third section. Should the ground between the two ditches not be able to absorb all the sewage discharged upon it, the overflow will be caught by the second distributing ditch, and if its quantity is sufficient can have its distribution regulated by the placing of a dam there as above.*

* The sources of information in regard to the sewage disposal at the London, Ont., Insane Hospital are :—(1) The 7th An. Rept. of the Prov. Bd. of Health (1888), which contains Col. Waring's Rept. to the Dept. Pub. Wks. and the Rept. of a Com. of Prov. Bd. Health, etc.; (2) Eng. & Bldg. Recd., vol. xx. (1889), p. 119 ; (3) a paper, "Disposal of Sewage at Large Institutions," in the American Architect for April 9, 1892. By Col. Waring.

CHAPTER XXXVI.

CHEMICAL PRECIPITATION AND INTERMITTENT FILTRATION AT THE ROCHESTER, MINNESOTA, HOSPITAL FOR THE INSANE.

THE original method of disposing of the sewage of this Hospital was by turning it directly into Silver creek, a small stream flowing a few hundred feet distant from the buildings. The pollution of the stream had been for a number of years, however, the subject of complaint on the part of the riparian owners. The matter was finally referred to the Minnesota State Board of Health, who directed Dr. Charles N. Hewitt, secretary and executive officer of the Board, to examine the case and report thereon. Dr. Hewitt reported that the discharge of crude sewage into the stream was the source of a serious nuisance which ought to be immediately abated.

The Controlling Board of the Hospital thereupon employed, in January, 1890, W. S. MacHarg, C.E., of Chicago, who proposed a scheme of chemical precipitation, supplemented by intermittent filtration. Mr. MacHarg's plans were submitted to the Controlling Board on February 5, 1890, and accepted by them, subject to the approval of the State Board of Health, which was given on February 21. Con-

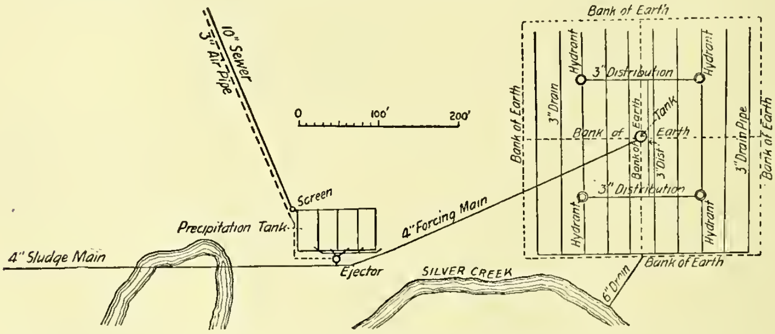


FIG. 87.—PLAN OF DISPOSAL WORKS, SECOND MINNESOTA HOSPITAL FOR THE INSANE, ROCHESTER, MINNESOTA.

struction was immediately begun and the works put in operation November 1, 1890. The general arrangement of the works and the creek are shown by Fig. 87. The detail of the precipitation tanks is shown by Fig. 88.

The present population of the Hospital is about 1,050 persons and the sewage, amounting to 60,000 gallons a day, flows to the precipitation tanks through a 10-inch pipe. The sewage consists only of the

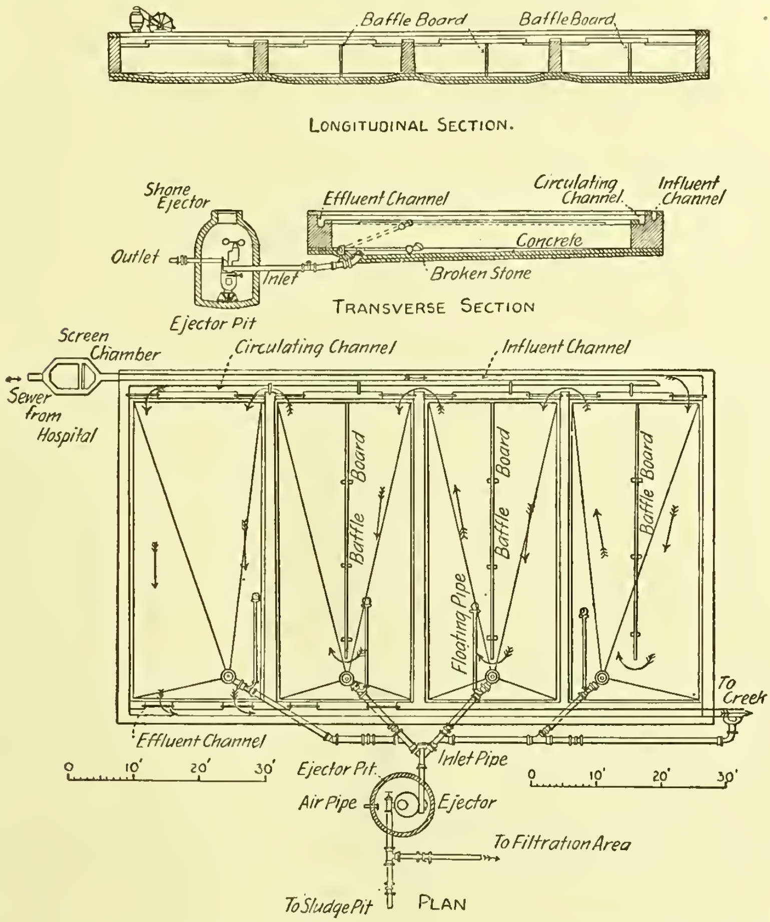


FIG. 88.—PRECIPITATION TANK, SECOND MINNESOTA HOSPITAL FOR THE INSANE.

discharge from water-closets, baths, toilets, kitchens, laundries, etc.; no storm-water is admitted. The tankage is of sufficient capacity to handle 75,000 gallons per day. The tanks, four in number, are arranged for a depth of sewage of 4 feet; they are worked on the continuous system, one being cut out each day and cleaned preparatory to receiving the sewage during the night, when steam is not available for pumping.

Shone's Hydro-Pneumatic Ejector is used for pumping; the air compressor and air receiver are located in the engine house, about

1,000 feet from the ejector, the air supply being carried thereto through a 3-inch pipe. The ejector is set low enough to allow the sewage and sludge from the bottom of the tanks to flow to it by gravity.

A 4-inch main leads from the ejector to the filtration area at the right, and also to the sludge disposal area, a short distance to the left. The soil of the filtration area is prairie loam to the depth of 16 inches, below which is sand and gravel. At about six feet is found a strong flow of ground-water in the direction of the creek. At this depth 3-inch underdrains are laid in lines about 25 feet apart, with the main outfall drain 6 inches in diameter, as indicated on the plan. No details of the method of laying these drains are furnished. The following from Mr. MacHarg's report will serve to indicate the other essential features of the project:

As a consequence of the reasons I have adduced, I recommend that a double process be used; that which is at the present moment the result of the best judgment of the facts which have accumulated from experience extending over many years and including many processes.

This process is, first, the clarification of the sewage by chemical precipitation or subsidence in tanks; and, second, the disposal of the effluent by intermittent filtration upon land, and of the sludge by mixture with earth as manure. The filtration of the effluent water is not essential except where a high standard of purity is required in the stream. It may therefore be so used advantageously during such part of the year as the ground is not frozen, and during extreme cold weather or during heavy rains may be discharged directly into the stream without offence.

The advantage of this process is, I think, obvious; the clarification in the tanks removes all suspended matter, which is the most offensive, and if proper chemicals are used for precipitation most of the dissolved impurity may be removed, and an effluent be obtained which may be discharged into any stream not used for domestic water supply without disagreeable consequences; the clarified effluent water may be used in irrigation to the advantage of crops, and almost all the dissolved impurity will be removed.

Having alternative ways of disposing of the effluent, you are thus made independent of climatic conditions, and the drainage of the hospital is continued without offence to adjoining property.

To accomplish this result I provide, as shown in the accompanying plans, a tank large enough to contain one day's flow of sewage for a probable 1,200 persons, or about 75,000 gallons (?); this tank is to be built of masonry or concrete, with partitions and channels so arranged that any one section may be cut out, emptied, and cleaned without interference with the continuous use of the tank.

. . . .

For the disposal of the effluent water I propose to underdrain about two acres of land, and prepare it with the necessary banks and channels on the surface. A pipe is to be laid from effluent end of tank to the ejector, and from the ejector to the field. This pipe will be branched as shown, and the sewage be allowed to flow over one portion of the field on one day and over another on the next. By dividing the field into four portions, each section has one day work and three days rest. By this intermittent use the extremely efficient action of earth filtration is obtained. A very ordinary class of attendance is required upon the filtration area. Certain crops may be grown upon this area, but this method is not founded upon any idea of getting a money value out of sewage.

To carry away the sludge deposited in the tanks an inlet pipe is connected to the ejector, branching and connecting to the bottom of each section of the tank, with an opening at the floor and with a branch with a floating arm. The floor connection is stopped with a plug and the arm is free to rise and fall with the water,

and the floating end covered with a screen. From the outlet of ejector a pipe is run to any part of the low land near the brook. A portion of land is excavated to receive the sludge. The section of the tank to be cleaned is closed off at the channels, and the clear water allowed to flow through the arm to the ejector and delivered on to the irrigating field; when the floating arm has fallen to the level of the sludge, the plug in the bottom is drawn out and the sludge discharged by means of the ejector through the pipe before mentioned upon the excavation prepared. When all the sludge is discharged the tank is washed out and the ejector disconnected from it, and the tank put again in service. The sludge is covered in the excavation with fresh earth and allowed to solidify; several layers may be put in each excavation, and when required may be dug out and used for manure.

As regards the use of chemicals to precipitate the sewage, and therefore render the effluent more nearly pure, I think that it will be necessary during the greater part of the year. While the effluent is being used upon the land, vegetation and bacterial action in the aërated soil will accomplish all that is necessary in the purification of the water, and you will only need to have recourse to the precipitants during such periods as you wish to discharge into the brook. This means necessarily through the winter and possibly during long-continued wet weather.

The chemicals most available are lime, sulphate of alumina, and, under some circumstances, sulphate or perchloride of iron. These are all used in the crude form, as purity and consequent increased cost are unnecessary. Clay is also used as an absorbent to facilitate deposition. Lime used alone is efficacious, but produces a sludge which under some circumstances becomes offensive. Sulphate of alumina with clay produces good results; with either mixture a small amount of one of the iron salts is sometimes used as a deodorizer. The experience with these preparations is mostly English, and as their sewage is less diluted than ours it is probable that you will need to determine the mixture which will give you the most satisfactory results.

The work was largely constructed by the labor of the hospital patients, and statements as to actual cost are lacking. For operating the works one man is specially employed, who is assisted somewhat, when necessary, by the patients.

A letter from the superintendent of the hospital, received in April, 1892, states that no trouble has been experienced in securing an efficient winter purification during the two winters that the disposal works have been in operation. Both the winters, however, are stated to have been somewhat warmer than the average. The sewage probably reaches the precipitation tank in cold weather with a temperature of at least 45° F.*

* The chief source of information in regard to the sewage disposal at the Rochester Insane Hospital is the 6th Biennial Rept. of the Trustees, etc., for the Biennial Period Ending July 31, 1890. Also see Eng. and Bldg. Record, vol. xxiii., p. 72.

CHAPTER XXXVII.

INTERMITTENT FILTRATION AT MARLBOROUGH, MASSACHUSETTS.

MARLBOROUGH, Massachusetts, a town with a population in 1890 of 13,805, is situated on the influent streams to Basin No. 3 of the Sudbury river water supply of the city of Boston. While the town has only just constructed a sewerage system, it has nevertheless resulted that Basin No. 3 has been considerably polluted by the drainage of Marlborough.

In 1888 an Act passed the Massachusetts Legislature authorizing the town of Marlborough to lay out, construct, and maintain a system of sewerage and sewage disposal. Under the provisions of this Act the town authorities designated M. M. Tidd, M. Am. Soc. C.E., of Boston, to prepare the necessary plans, which, after a number of hearings, were finally approved by the State Board of Health on January 7, 1890. The plans presented by Mr. Tidd included the delivery of the sewage completely outside of the Sudbury river water-shed and its purification by intermittent filtration. In consideration of carrying the sewage outside the Sudbury water-shed the Boston Water Board have agreed to contribute $62,000 toward defraying the expenses of the work of construction. Desmond FitzGerald, M. Am. Soc. C.E., represented the city of Boston in this connection. The sewerage system, which is of the separate type, was completed early in 1892, and the disposal area shortly afterward.

On June 23, 1892, there were about 350 sewer connections. As the total number of water connections at the close of 1890 was 1,794, and the population of the town in 1890 was 13,805, it is evident that the amount of sewage to be purified is small compared with what it will be in the future.

The town introduced water-works in 1883, and the consumption of water in the early part of 1892 was about 325,000 gallons a day, but at 4.30 P.M., May 12, 1892, after a dry spell, the flow through the outlet sewer was at the rate of 330,000 gallons a day, and on May 25, 1892, at 9 A.M., after heavy rains, the rate of flow was 790,000 gallons a day. The measurements on each date were made by observing the time taken to fill the separating tank once.

Ground-water is the only explanation for this large flow through the sewers, for, as has been stated, not more than one-fifth of the water

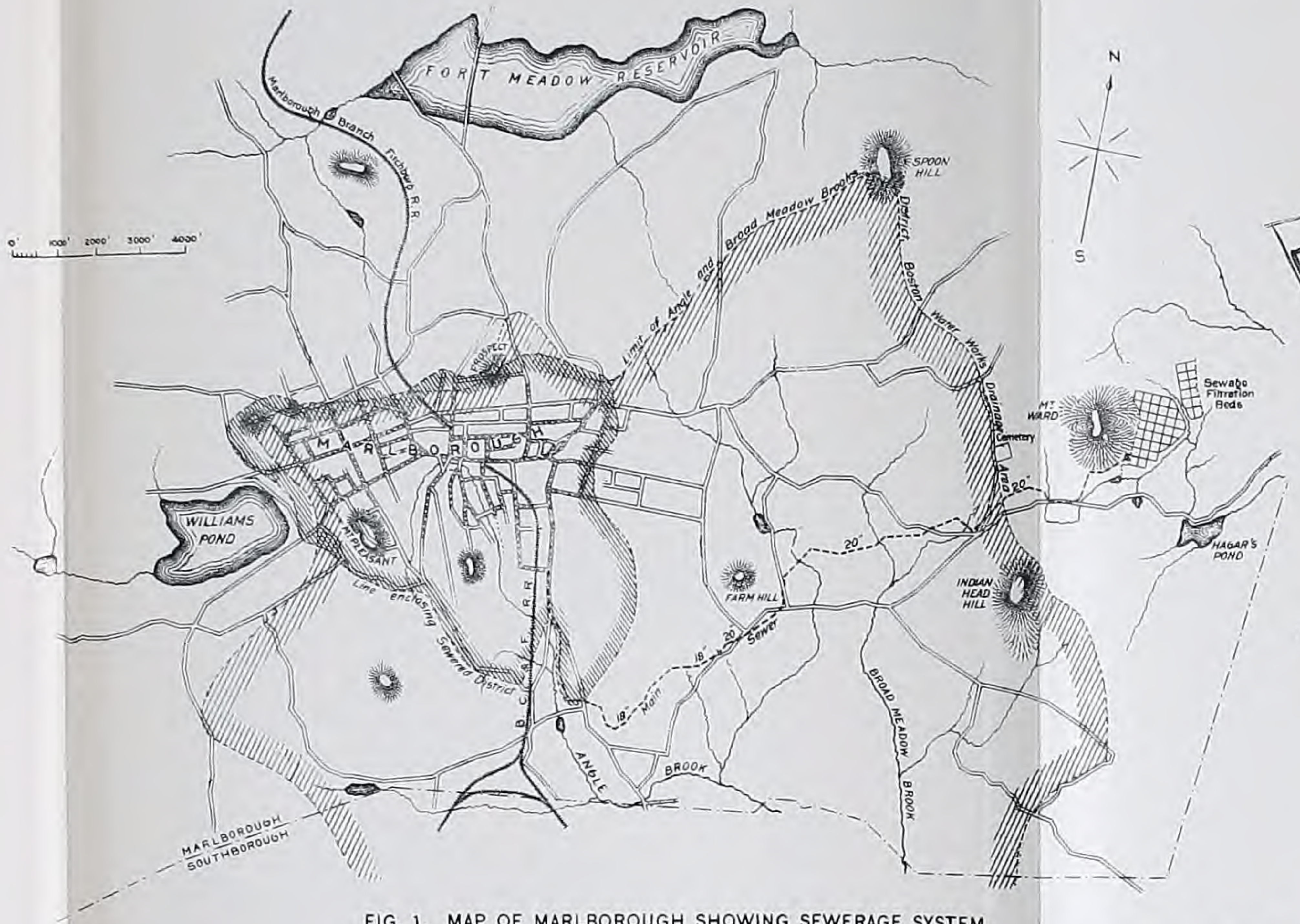


FIG. 1. MAP OF MARLBOROUGH SHOWING SEWERAGE SYSTEM.

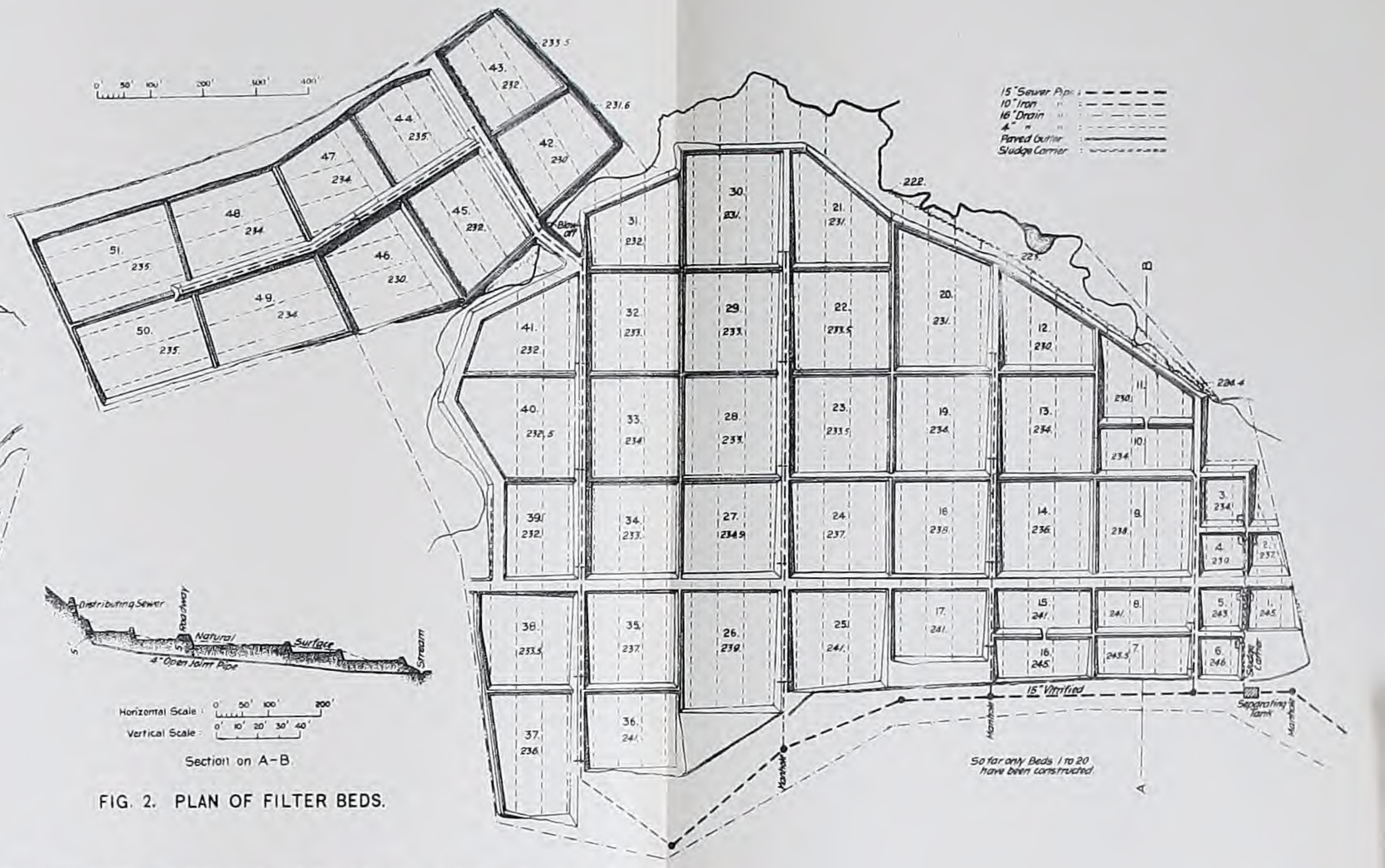


FIG. 2. PLAN OF FILTER BEDS.

CHAS. HART & SONS, LITH., 36 VESEY ST., N. Y.

PLATE V. MAP OF MARLBOROUGH TOWN AND PLAN OF FILTER BEDS.

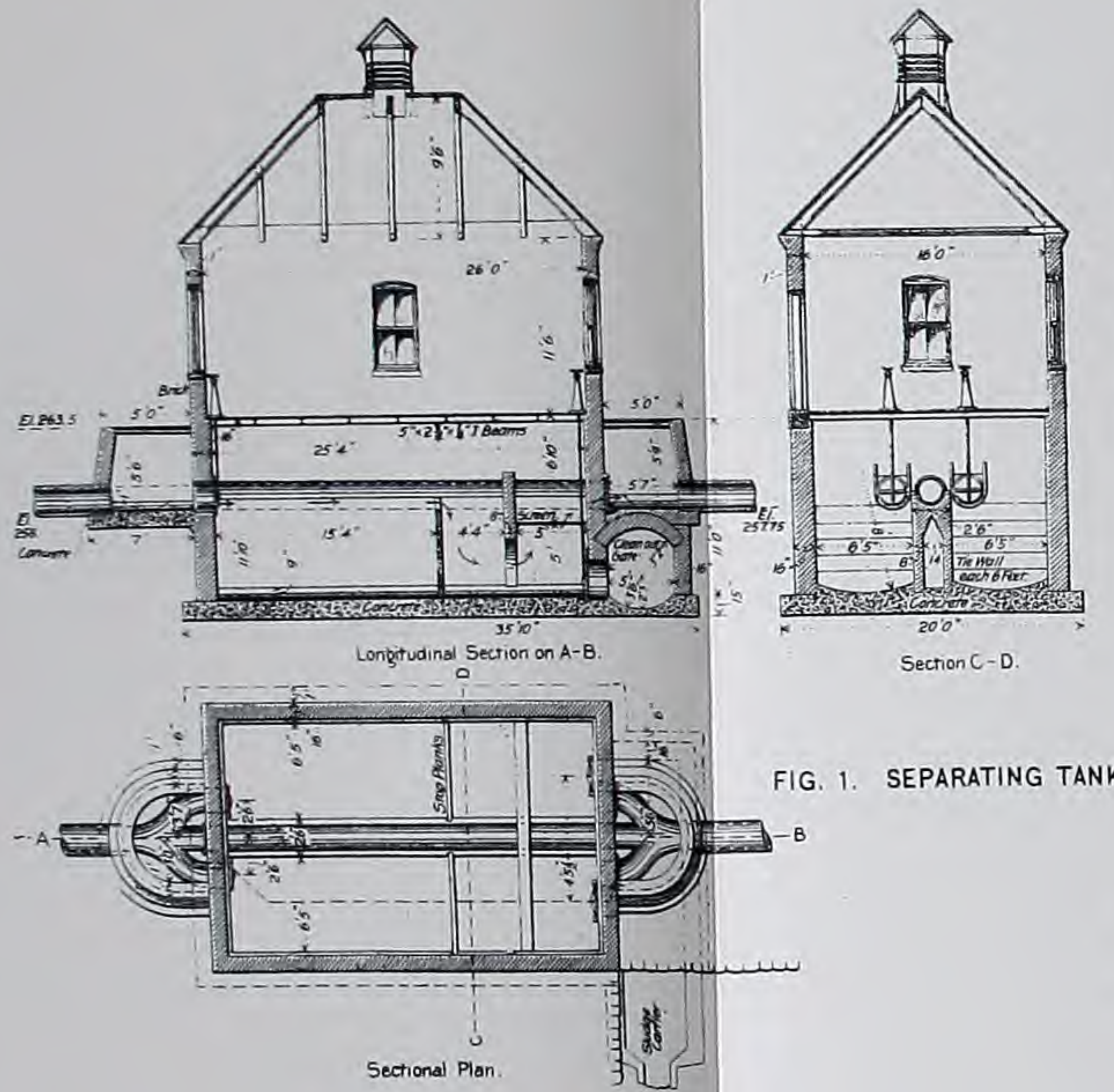


FIG. 1. SEPARATING TANK.

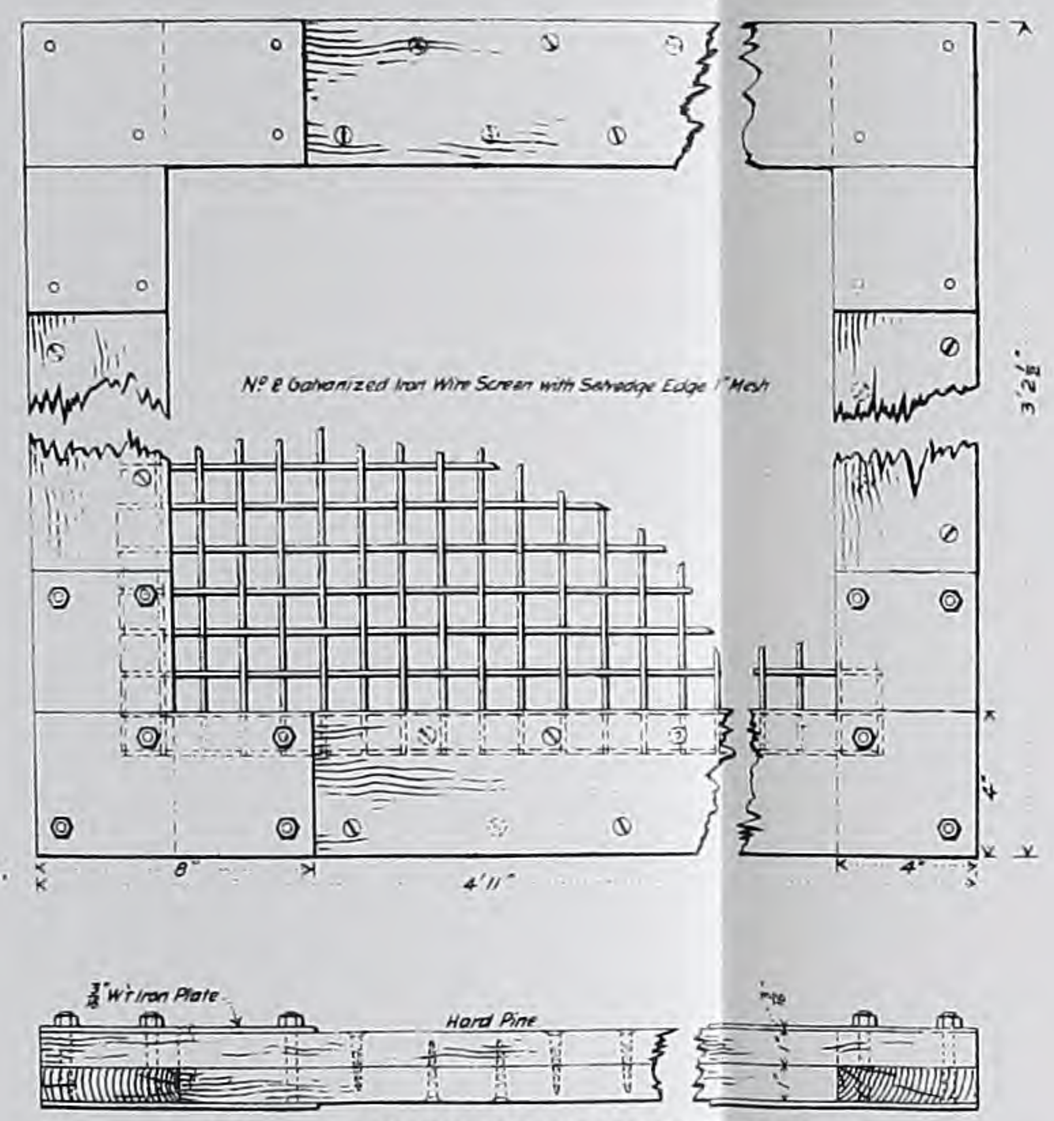


FIG. 4. SCREENS IN SEPARATING TANK.

PLATE VI. DETAILS OF SEWAGE PURIFICATION PLANT AT MARLBOROUGH, MASS.

CHAS. HART & SONS, LITH., 36 VESEY ST., N. Y.

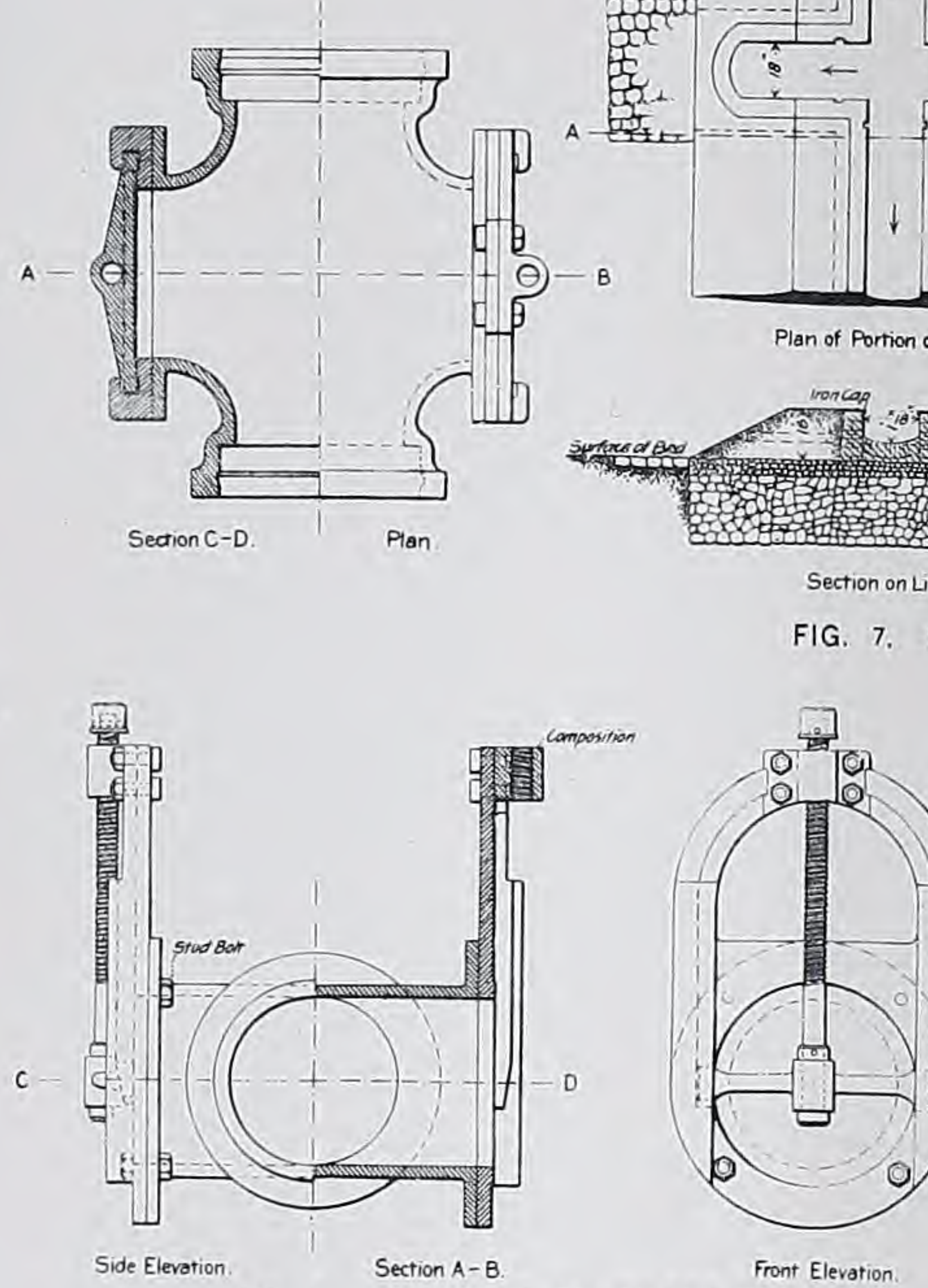


FIG. 6. 10-IN. GATE TO FILTER BEDS.

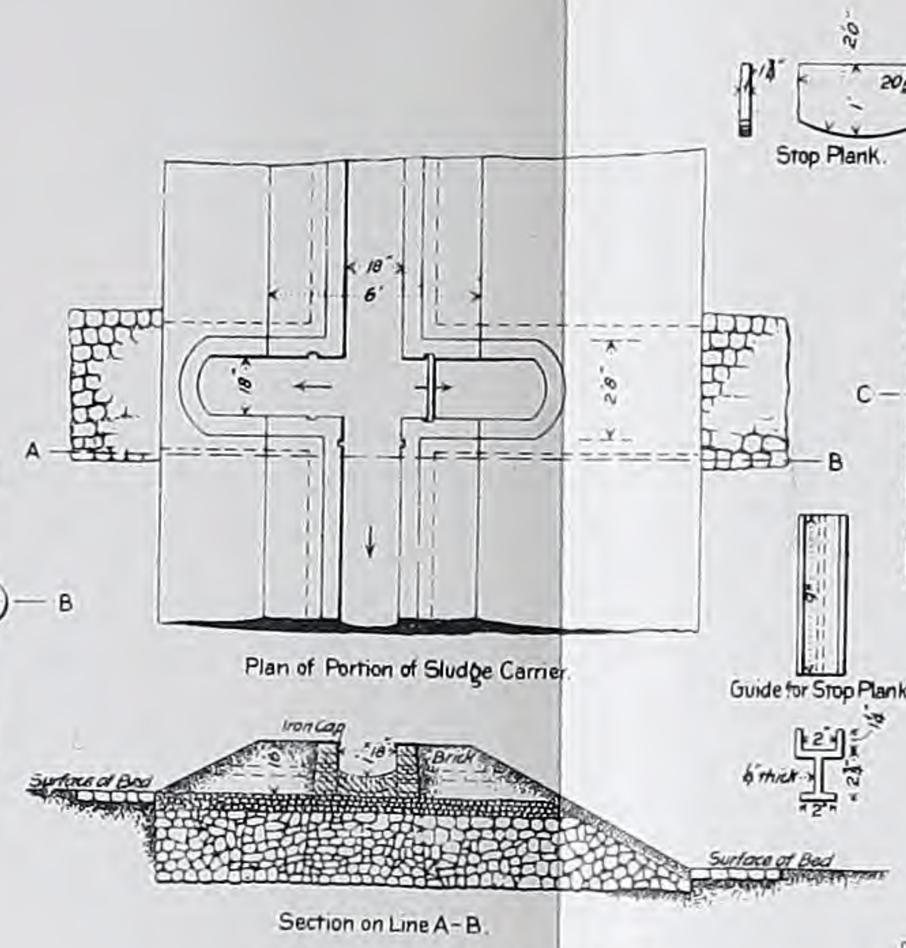


FIG. 7. SLUDGE CARRIER.

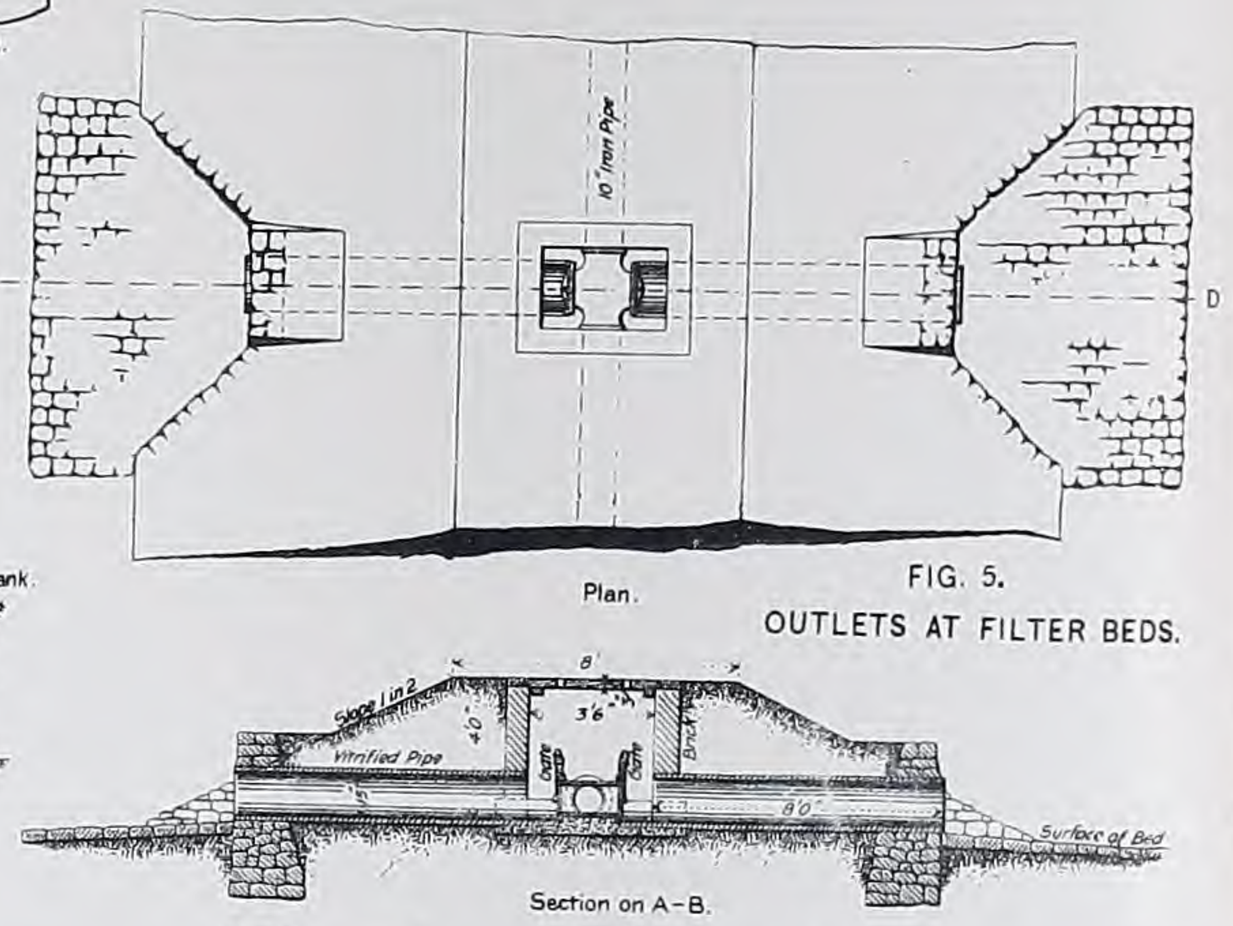


FIG. 5. OUTLETS AT FILTER BEDS.

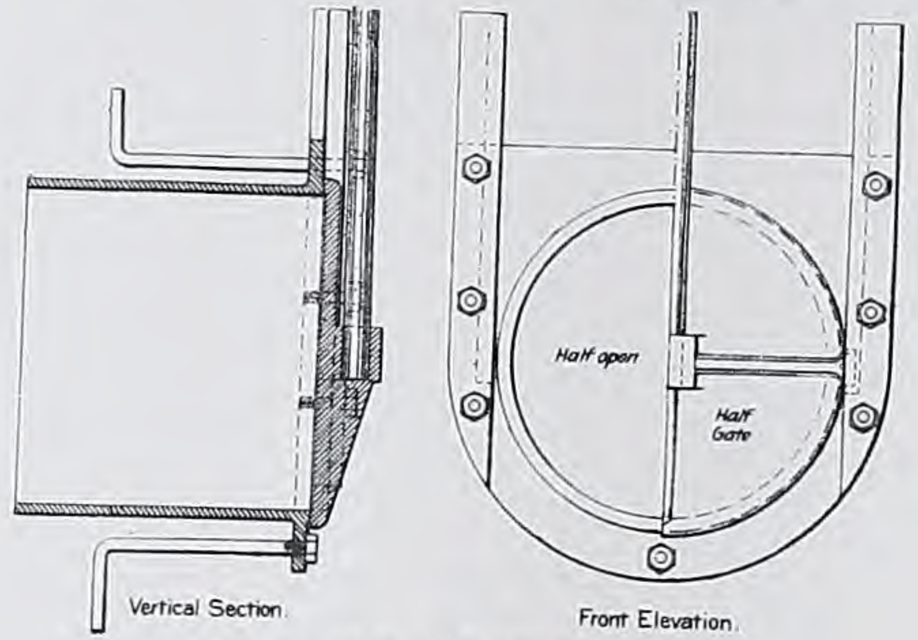


FIG. 2. 18-IN. INFLUENT GATE.

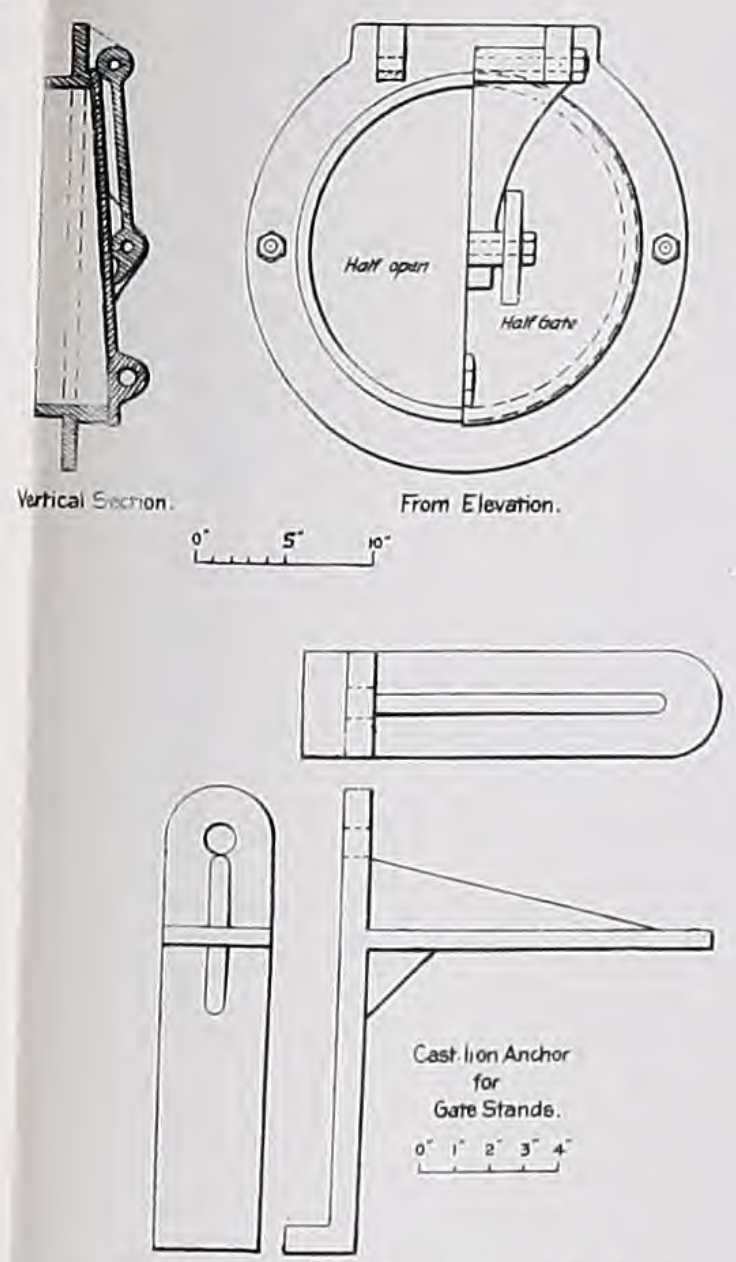


FIG. 3. 18-IN. SWINGING GATE.

consumers are connected with sewers. Unfortunately, Marlborough is not the only town where an excessive amount of ground-water finds its way into the sewers. The city of Boston would not allow Marlborough to put in underdrains because it feared that sewage would pass through defective sewer joints, and into the drains, and thus finally into the Boston water supply.

The filtration areas are located about two miles, in an air line, from the outskirts of the village, as shown by Plate V., Fig. 1, and some $3\frac{1}{2}$ miles from the last house connection, measured on the pipe line. The nearest house is about 1,000 feet from the filter areas. There are two other houses about 1,500 feet away, and no more within about a mile.

The sewage passes from the village to the disposal area through an outlet sewer of vitrified pipe. A separating or settling tank removes the sludge from the sewage, after which it passes through iron pipes to the several filter beds, of which there are now 14 in use besides the six small ones used for emptying the sludge.

The arrangement and details of the purification plant are shown by Plates V. and VI. Fig. 2, Plate V., is a plan of the filter beds. Only 20 of these, including the 6 sludge beds, were in use, but it is proposed to use 51 beds eventually. The 14 filter beds now in use, with their dividing embankments, cover about 13 acres. In the whole tract bought by the city there are 60 acres.

The separating or sludge tank is shown in plan and section by Fig. 1, Plate VI. It is of brick, in two compartments, with gates permitting sewage to be admitted to or drawn from either one at will.

The course of the sewage in passing through the tank is shown by the drawings. The screens perform only a slight service, as most of the solid matter settles before the sewage reaches the screens.

The sludge can be removed from either tank to the sludge carrier by opening the cleaning-out gate. The floor over the tanks is formed by iron gratings supported by I beams, $3\frac{1}{4}$ feet centre to centre.

The character of the 24-in. influent gates, and the 18-in. gate, which controls the passage of sewage directly to the beds through the pipe on the partition wall, are shown by the 18-in. lift-gate, Fig. 2, Plate VI.

There is also shown in Fig. 3, Plate VI., an 18-in. swinging gate, which is apparently used at the effluent end of the tank.

Fig. 4, Plate VI., shows in detail the screen used in the separating tank.

The sewage passes from the top of the tank through iron pipes along the embankments to the several beds, and discharges on to the beds through gates and short branches, the bed at the point of discharge being paved. Fig. 5, Plate VI., gives a plan and section of the outlet to the beds, and Fig. 6, Plate VI., shows the two-way 10-in. ver-

tical gate used. A single gate constructed on the same principle as the two-way is used where only one gate is needed.

The sludge passes through the cleaning-out gate, already mentioned, to the sludge carrier, shown in detail in Fig. 7, Plate VI.

Sludge was first removed from the tank in April, 1892. It remained upon one of the beds for a month, instead of being speedily removed, and finally became offensive. An adjacent farmer removed it without cost to the town. On May 25 the sludge was drawn from the tank the second time, and on June 11 the third time, in each case a farmer hauling it away. The tank filled full, or nearly full, of sludge, each of the last two times.

The crust that forms on top of the filter beds, consisting of minute particles of matter suspended in the sewage, is harrowed in from time to time.

The effluent from the beds discharges through underdrains into Hop and Wash brooks, which empty into the Sudbury river. These beds were visited by Mr. Baker, June 17, 1892, at which time they seemed, so far as casual observation could determine, to be doing good work and presented no unpleasant features. A strong breeze was blowing over the beds, but even at their leeward side only a slight odor was noticed.

The cost of the tank, tank-house, filter-beds, and all appurtenances, including engineering and excluding land, was $21,720. The outlet sewer was carried $2\frac{1}{2}$ miles farther than it would have been had not sewage purification been adopted. The total extra cost caused by the construction of this extra pipe line and the filtration beds and appurtenances was about $62,000, which was met by the city of Boston in return for the removal of the sewage from its water-supply.*

* See Eng. News, vol. xxviii., p. 170 (Aug. 25, 1892).

CHAPTER XXXVIII.

INTERMITTENT FILTRATION AT THE MASSACHUSETTS SCHOOL FOR THE FEEBLE-MINDED.

THE Custodial Ward of the Massachusetts School for the Feeble-Minded, completed in 1889, was designed to accommodate about 150 inmates. It is located near the summit of a densely wooded hill in Waltham. The natural course of the drainage from the School is into the Charles river, which is the source of a municipal water supply, at a point a short distance below where the drainage of the Custodial Ward would naturally enter it. Under the laws of Massachusetts, to which we have already referred (p. 480), it therefore became necessary to purify the sewage before allowing it to flow into any tributary stream of the Charles river. Frank P. Johnson, C.E., of Waltham, was accordingly directed to prepare plans for sewage disposal.

The plan prepared by Mr. Johnson and carried out was as follows:

From the Custodial Ward building and the laundry just south of it the sewage is conducted into a brick sludge-trap, shown in detail by Fig. 89, where it halts until the grease has risen in a scum to the surface, the insoluble matter settled to the bottom, and the paper, etc., become broken up and held in suspension. The 6-inch inlet enters about a foot above the surface of the sewage. From the sludge-trap a 4-inch ventilating pipe runs into the boiler-house chimney. The 5-inch iron overflow from the sludge-trap to the detaining tank is T-shaped, and so placed as to allow the effluent to pass over from below the scum of the grease on the surface and from above the sediment at the bottom of the sludge-trap. An 8-inch iron pipe and gate at the bottom of the sludge-trap permits the grease and sediment to be run off to a compost heap as often as may be necessary—probably about once in three months.

From the sludge-trap the sewage passes into a brick detaining tank, 13 by 20 feet, capable of holding the sewage of 24 hours, amounting to 16,000 gallons. The bottom of this tank pitches every way to one corner, where is placed a 4-inch gate through which its contents may be discharged when desired, and a siphon through which the tank automatically empties itself as often as it becomes full. Above, in the same corner, is an overflow opening for use in case the siphon becomes clogged, and it is so placed that the interior of the detaining

tank may be viewed through it from the adjoining man-hole. The 4-inch gate and the siphon are in this man-hole, the bottom of which is one foot lower than the lowest joint inside the detaining tank, so as to facilitate the action of the siphon. The siphon is primed by a priming cup on its longer leg, and at its top it is provided with a special arrangement for cleaning should it become clogged.

From this point the sewage flows into and through a small distributing man-hole, out of which lead three earthenware pipes controlled

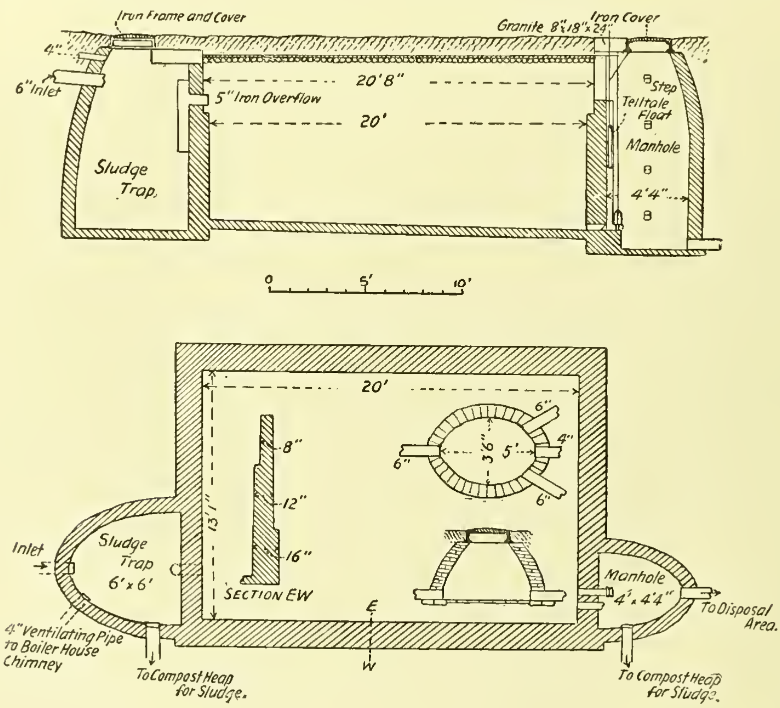


FIG. 89.—DETAILS OF DETAINING TANK, MASSACHUSETTS SCHOOL FOR THE FEEBLE-MINDED, WALTHAM.

by as many gate valves. The sewage, if necessary, may be run through one of these pipes out over the hillside among the dense underbrush of the woods before mentioned, but each of the other pipes supplies a filtration area, of which there are two, so that one may be at rest while the other is in service. A description of one will answer for both.

The subsoil of the hillside is gravel that would be excellent for road-making, and is overlaid by about 18 inches of loam. Averaging about six feet from the surface is rock. This condition, while not the most favorable, had to be made the best of, and it was first under-

drained with ordinary 2-inch circular land tile, laid five feet deep on lines 50 feet apart following the direction of quickest descent, the tile being extended far enough above the disposal area to intercept what

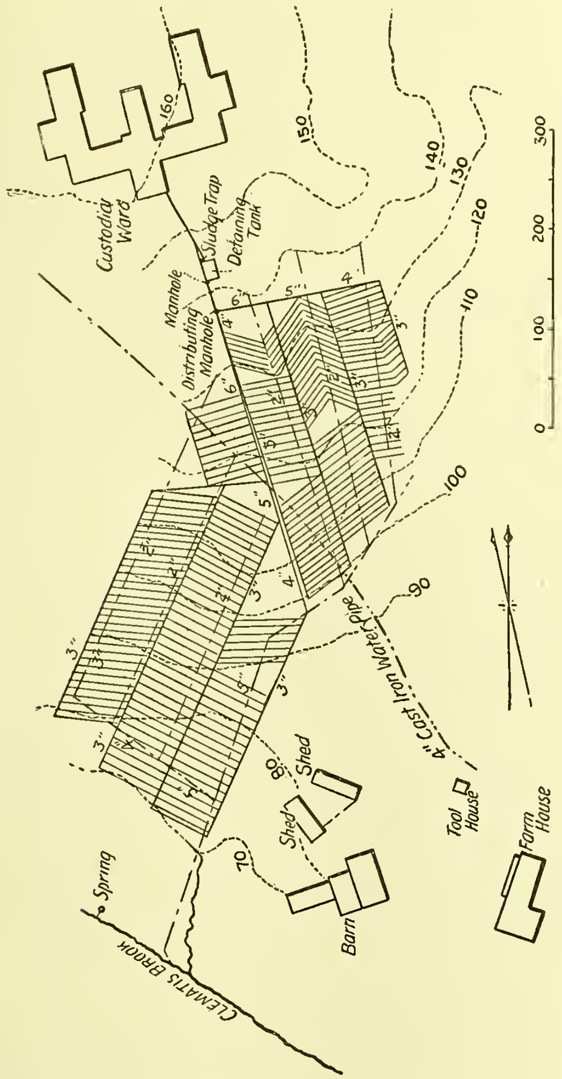


Fig. 90.—Plan of Disposal Works, Massachusetts School for the Feeble-minded.

storm water might come from the hillside above. These underdrains discharge into Clematis brook, a tributary of the Charles river, and receive no sewage except as the purified effluent may enter them after filtration. A general plan of the disposal works, including the filtration area, is shown by Fig. 90.

From the distributing man-hole the sewage passes into 6-inch mains, which deliver into 3-inch feeders laid in parallel lines approximately at right angles to the contour lines, or, in other words, on the lines of greatest slope.

Every three feet on each feeder is a 3-inch T-branch connecting with a ∩-lateral, and set level, or even slightly pitching up-hill, so as to cause each lateral to be filled in succession before the flow reaches the next. The ∩-laterals are approximately parallel, and follow the contour lines of the surface about three feet apart. They are covered just deep enough to permit of ploughing the field without disturbing them. About 5,000 linear feet of laterals have been laid in each disposal area.

The several dotted lines on Fig. 90, numbered from 70 to 160, are contours showing elevation of surface. For greater distinctness and convenience only every other one of the laterals has been drawn. The filtration system is shown in full lines and the underdrains in broken and dotted lines.

No separate account was kept of the cost of doing the work, its execution being mostly at odd times by laborers elsewhere at work on the grounds, as it became convenient to spare them. This was by no means to the advantage of the sewerage system.

The engineer's estimate of cost was $1,500, and the probable real cost could not have been far from $1,800. It is likely that it could be duplicated under ordinarily favorable conditions for $1,400.

For the sake of economy a similar but slightly different device from the tile distributors was used, and a material saving effected.

The works were first operated January 1, 1890, and are reported as giving good satisfaction.*

* The foregoing account of the sewage disposal at the Mass. School for the Feeble-minded is derived from a description by Mr. Johnson originally contributed to Eng. and Bldg. Recd., appearing in vol. xxi., at page 300. Mr. Johnson has kindly revised the matter there given, for use here.

Since this chapter was written permission has been granted by the legislature to connect the sewers of the school with the sewerage system of the city of Waltham. The legislative act was approved March 10, 1893.

CHAPTER XXXIX.

SUB-SURFACE IRRIGATION AT THE LAWRENCEVILLE, NEW JERSEY, SCHOOL FOR BOYS.

THE Lawrenceville School for Boys is located at Lawrenceville, New Jersey, a small town about half-way between Trenton and Princeton. The late John C. Green left the bulk of a large fortune to trustees to be used by them for educational and other purposes. In 1882 the trustees purchased the Lawrenceville School, and proceeded to erect new buildings and make other constructions necessary for placing the institution upon a thoroughly first-class footing. Messrs. Peabody & Stearns were designated as architects to design and superintend the erection of the buildings; Frederick Law Olmsted was commissioned to lay out the grounds; and to J. J. R. Croes, M. Am. Soc. C.E., was intrusted the design for the water supply, sewerage, and sewage disposal works, which latter were constructed under the personal supervision of Frederick S. Odell, M. Am. Soc. C.E., who acted under the direction of Mr. Croes.

The following is the description, slightly condensed, of the sewerage and sewage disposal works as given by Mr. Odell:

The necessity of disposing of the sewage within a limited area of the grounds made it imperative that its volume be limited to a minimum, and therefore all surface or subsoil drainage was excluded from the sewers, and disposed of as previously related; then, to insure positive immunity from leaky joints, it was decided to use six-inch cast-iron pipe, with leaded joints, for the sewers.

. . . .

There are two branch lines of sewers, with a flushing man-hole at the head of each. . . .

The two branch sewers unite near the rain-water reservoir and continue to the boiler-house and laundry, near which is placed the sewage tank, in which the solid matter in the sewage is allowed time to deposit itself on the bottom, and the partially clarified liquid is retained until it is desirable to discharge it into the sub-surface tiles.

SEWAGE DISPOSAL SYSTEM.

The sewage tank is built of brick-work underground, and is in two sections. The first or retaining section is in duplicate, and contains six compartments, three in each set. Each compartment is sixty feet long, about three feet wide, and four feet deep. [See Fig. 91.]

The sewage flows into one end of the first compartment, passes along its whole length, and at the other end passes into the second compartment through a quarter-bend pipe, with the mouth turned down below the level of the outlet, to prevent scum on the surface of the liquid from passing over into the second compartment, through which the liquid passes to its further end, and in like manner into

the third, at the further end of which it passes over a weir into the receiving chamber, which is circular in form, twenty-five feet in diameter, and eight feet deep. From this it is pumped by a pulsometer pump as often as necessary. This

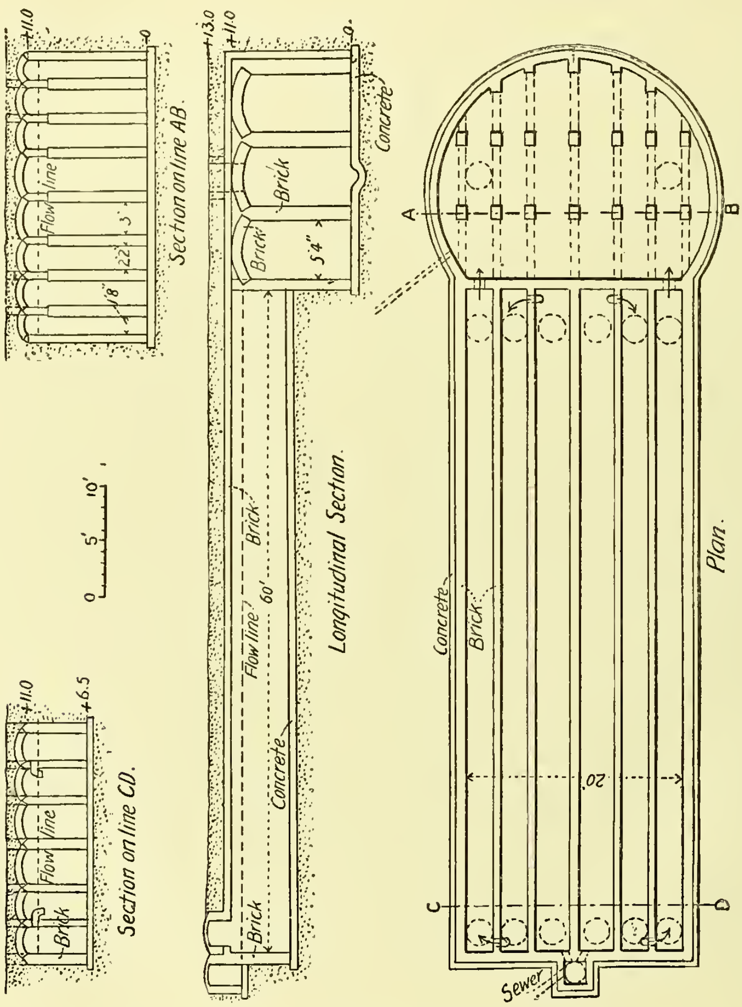


FIG. 91.—PLAN AND SECTIONS OF RECEIVING AND SETTLING TANK, LAWRENCEVILLE, NEW JERSEY, SCHOOL.

chamber is ventilated by a pipe leading into the flue of the boiler-house chimney. It is intended that whenever solids collect in such quantities that the settling compartments require cleaning, the sewage shall be turned in the duplicate set and the sludge removed from the first.

It is found that nearly all the solids are deposited very near the entrance in the first compartment, and to cause the deposit to be distributed more evenly over the bottom the water in the first compartment has been siphoned into the receiving chamber two or three times within the past six months. The rapid subsidence of the water, and the flow of incoming sewage during this operation, distribute the solids over the bottom, and enable the compartment to be used longer without cleaning out than would be the case if this distribution were not made.

The pulsometer has been so arranged that by attaching a suction hose the water in the settling tanks can be pumped out and carried 300 feet through a hose to farm land ploughed to receive it. In January, 1887, the tanks were thus emptied and the sludge then removed by a farmer to whom it had been sold. There were about 300 cubic feet of sludge removed from the first section of each of the settling tanks.

The irrigation ground [see Fig. 92] comprises about one and three-quarters acres in the lower part of the school grounds, between the boiler-house and the brook. It is still further limited in location by the dam and pond on the westerly side, and an adjoining owner on the easterly side. It is the lowest portion of the school property, is naturally wet, and that portion near the brook (before drainage) was swampy. Its selection was a matter of necessity, it being all the land available for this purpose.

The natural surface of the ground was on a quite uniform slope from the higher portion to the brook, so that very little surface grading was necessary, but its thorough subsoil drainage became of the greatest importance.

To accomplish this, parallel lines of 2-inch round agricultural tile were laid, 40 feet apart, discharging into the brook.

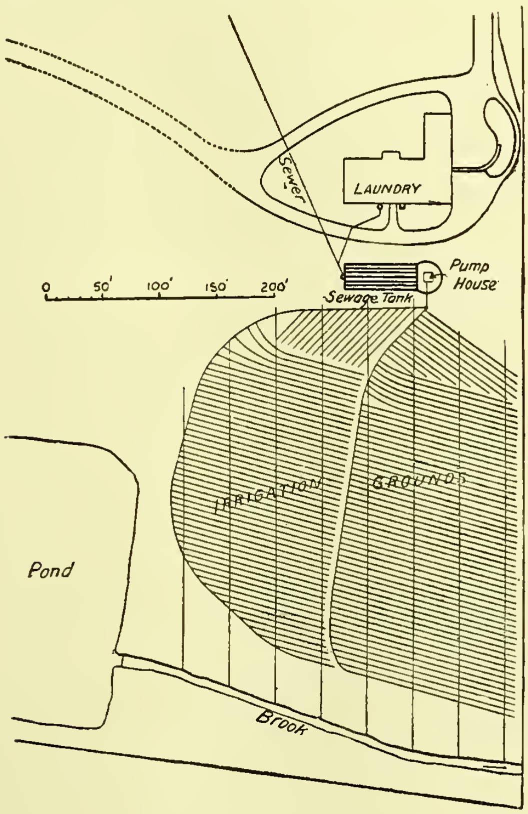


Fig. 92.—Plan of Disposal Works, Lawrenceville School.

These drains were laid 4 feet below the surface wherever the elevation of the brook permitted this depth; but, by reason of the elevation of the brook, the lower part of the drains were not deeper than from 2 to 2½ feet, and probably the average depth is not greater than 3 feet.

These drains were effective in drying the ground and preparing it to receive the sewage.

The distributing or sub-surface tiles were laid about eight inches below the surface, in nearly parallel lines 5 feet apart, on uniform grades of 9 to 12 inches in 100 feet. [See Fig. 92.]

They are 2 inches in diameter and 12-inch lengths.

They are laid on bed pieces of the same material and length, which cover the bottom joints. Smaller pieces cover the top joint, leaving an opening on each side of $\frac{3}{4} \times \frac{1}{8}$ inch, out of which the water escapes into the soil.

The water enters these lines of sub-surface drains from a 4-inch carrier leading from a chamber into which the pulsometer discharges, and in which are the two 4-inch carrier pipes leading to different parts of the ground, into either of which the sewage can be turned at pleasure and the two sections of the field used alternately.

A special branch joins the 2-inch distributing tile with the 4-inch carrier, the 2-inch tile being so attached that its bottom is at the same level as that of the carrier from which it branches, so that if but little sewage is flowing in the carrier each line of drain will get its share, those in the upper portion of the field being prevented from surcharge by either flattening the grade or throttling the first section of drain.

There are about six hundred feet of 4-inch carrier pipe, and about twenty thousand feet of 2-inch drains on the $1\frac{3}{4}$ acres of ground.

The amount of sewage water averages 6,000 gallons a day.

This is discharged into the irrigation tile eight times in a month, or from 20,000 to 25,000 gallons at a time. The discharge from the outfall drains begins very soon after the tile is charged, showing the ground to be very porous.

No complaint has been made of any offensive odor or fouling of the stream.

The irrigation ground is not worked to nearly its capacity, as it has been found that the sewage does not flush the tiles fully to the lower extremity of the lines; and while the growth of the grass on the upper end of the lines is luxurious and rapid, the ground over the further end has remained bare or with very scanty vegetation.

. . . .

The cost of the following structures is made up from accounts kept during construction:

. . . .

Sewage tank	$2,100
Irrigation grounds	2,000

With the exception of the occasional deficiency in the capacity of the rain-water drains, . . . the operation of the works during the year has been very satisfactory.

The regular number of persons now using the water and contributing to the sewage is 180. The works are designed to accommodate 400 people.

The water supplied for all purposes averaged 8,000 gallons a day in 1886, varying from 6,000 gallons a day in April to 25,000 gallons a day during one week in October, 1886, when the lawns were very dry and a new sprinkling cart was put in use on the roads and lawns.

The amount of sewage at Lawrenceville has gradually increased, until, in 1893, it averages, during the school terms, about 20,000 gallons per day. Some complaints having been made for the last two years that the effluent is insufficiently purified as it enters the brook, the progressive management of the school determined to extend the sewage disposal facilities. The work was again intrusted to Mr. Croes, but in order to obtain the views of other engineers, opinions were asked from Mr. Allen Hazen and Mr. Rafter. Both of these gentlemen visited Lawrenceville and submitted short reports to Mr. Croes of the

results of their examinations. Mr. Rafter was there on July 24, 1893. At that time the school was not in session, and the daily amount of sewage averaged only five or six thousand gallons per day. The original disposal area appeared capable of still handling this amount, although the effluent, as it issued from the drains, gave some evidence of incomplete purification. Several of the distribution tiles were removed and found nearly clear from deposit, a result largely due, without doubt, to the thorough settling which takes place in the deposit chambers.

Mr. Croes had suggested for the additional disposal works the use of intermittent filtration through specially prepared areas, the soils at Lawrenceville being of a heavy clayey nature—entirely unsuited of themselves—and material suitable for intermittent filtration can only be obtained at a distance of about two miles from the school. In view of this fact, Mr. Hazen, while approving of the intermittent filtration, suggested as a considerably less expensive alternative the use of broad irrigation on a field of several acres included in an area of land which the school had recently purchased. The water of the brook receiving the effluent is used for watering cattle on the adjoining farms, and in view of the uncertainty as to the degree of winter purification attained in broad irrigation, Mr. Rafter suggested that the intermittent filtration would be, on the whole, preferable by reason of giving somewhat better control of all the conditions.

All the engineers agreed that the present sub-surface irrigation area, which is now considerably in need of rest, should be retained for use as a relief area. With such assistance it was considered that a filtering area of about 22,000 square feet of the available material would be sufficient for a number of years. The matter is still in abeyance, but it may be stated that under the conditions, by due attention to the detail, a fairly satisfactory result can be attained, whichever method of treatment may be used.*

* The experience of the past eight years has shown that the subsoil tile were laid on rather too steep a grade, so that when the system was filled up with an overdose of sewage, the water rose to the surface at the lower ends of the lines of tile. To obviate this, it was considered best to insert two additional lines of carriers intercepting the lines of tile at half their length and thus reducing the head on the ends when the system was full. The outfall underdrains which, owing to local conditions, as above stated, had apparently not been laid deep enough below the subsoil tile, were cut off by an intercepting drain laid parallel to the brook and 20 feet from it, and continued 1,000 feet down stream, the trench being partly backfilled with cinders. The effluent sewage filters away slowly into the brook. This portion of the work was done in August, 1893. It is contemplated to construct the additional filtration area of underdrained gravel filled trenches at an early day.

For sources of information in regard to sewage disposal, etc., at the Lawrenceville School, see (1) Mr. Odell's paper on The Water Supply, Drainage, and Sewerage of the Lawrenceville School, in Trans. Am. Soc. C.E., vol. xvi. (1887), pp. 68-78; (2) Eng. & Bldg. Recd., vol. xv. (1886), pp. 12-18.

CHAPTER XL.

INTERMITTENT FILTRATION AT GARDNER, MASSACHUSETTS.

An intermittent filtration system was put in operation in 1891 in connection with the new sewerage system. McClintock & Woodfall, of Boston, were engineers for the works. The plant has been described as follows: *

The town of Gardner is situated in the central part of the State, on the divide between the Connecticut and Merrimac rivers, all but a small part draining into the Connecticut river. The population of the town in 1890 was 8,424. It is largely engaged in the manufacture of chairs. The daily consumption of water is about 300,000 gallons.

The town is made up of four villages closely united—South, Depot, West, and Centre. Of these the West village is the most thickly settled and contains the most factories. The South is also thickly settled and has a number of factories. The Centre is strictly a residential part of the town. The Depot village is not thickly settled.

The State Board of Health, fearing that in time the crude sewage, if emptied into the brook leading to Otter river, might create a nuisance, ordered the town to purify the sewage before allowing it to flow into the river. Intermittent downward filtration was adopted. The main outfall sewer is a 12-inch pipe. A greater part of West Gardner, the Centre and Depot villages had been sewered at the beginning of 1893.

The separate system was used not only on account of its costing less than the combined, but from the fact that the surface water can be at this place easily and cheaply drained into natural water-courses without doing any harm.

There were in use, at the close of the summer of 1892, 5½ miles of sewers, 12 to 6 inches in diameter, 128 man-holes and 23 flush gates in man-holes; also 139 sewer connections, of which 100 were from houses, 25 from business blocks, 10 from factories with a total of 1,500 employees, and 4 from hotels. At the close of the summer of 1891 there was a total of 97 connections. The daily amount of sewage delivered at the filter beds was about 125,000 gallons in February, 1893.

* Condensed from Eng. News, vol. xxix., pp. 163-165 (Feb. 16, 1893).

To reach the most available ground for a filter area it was necessary to carry the outlet sewer down through a small valley and up on to a hill. This was effected by making the last 1,050 feet of the

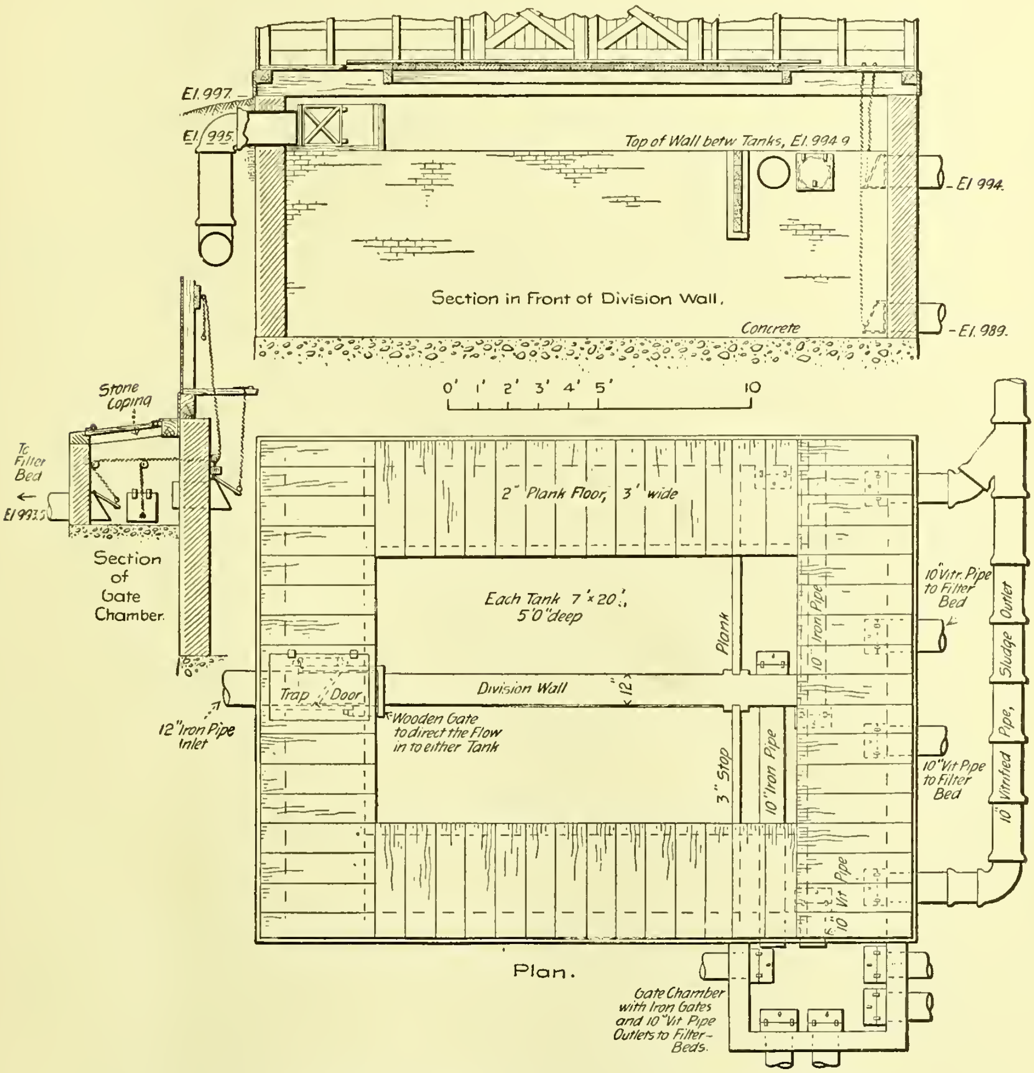


FIG. 93.—PLAN AND SECTION OF SETTLING TANK, GARDNER, MASSACHUSETTS.

outlet sewer of iron pipe, with a sag near the middle of 24 feet. A blow-off, discharging on to filter bed No. 50, Fig. 96, used only in this connection, was placed at the lowest point in the iron pipe. This is to be used only in case of stoppage. In February, 1893, this

gate had not been open for over a year, and no trouble had arisen from solids collecting at this point and stopping the sewer.

The blow-off gate used is an 8-inch vertical lift gate, exactly like the 10-inch in use at the filter beds at Marlborough, Massachusetts, shown on Plate VI., Fig. 6.

The outlet pipe discharges into a settling tank, shown in plan and

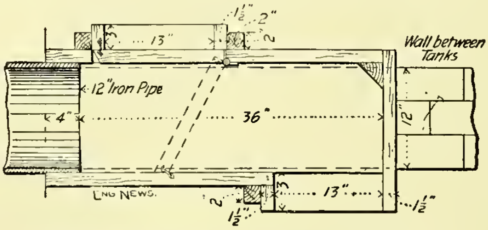


FIG. 94.—INLET TO SETTLING TANKS.

section by Fig. 93. The tank is built of brick, with walls 12 inches thick. It is divided into two parts by a 12-inch wall, built through the centre, thus giving two compartments, each 20 feet long, 7 feet wide, and 5 feet deep. The sewage first flows into a wooden box,

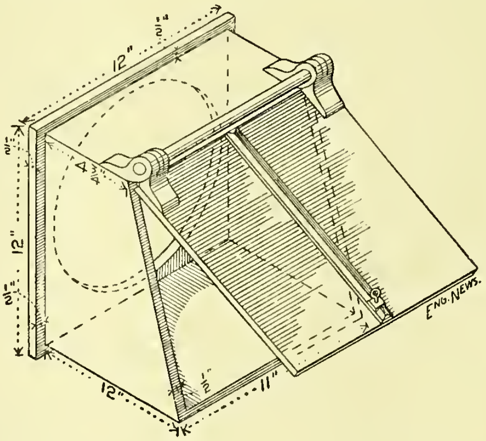


FIG. 95.—GATES ON OUTLET PIPE FROM TANK.

shown in plan by Fig. 94, and also by the dotted lines in the plan of the tank, Fig. 93, and is diverted into either tank by means of a swinging door. Stop planks to prevent floating matter from reaching the gate chambers are placed near one end of the tanks. The sewage is drawn off at the surface by means of pipes leading into the gate chamber. The flow into these pipes is controlled by iron gates, a sketch of which is shown by Fig. 95. The sludge is drawn

off by opening similar gates, shown in plan at the bottom of the tank, Fig. 93, crude sewage being used to wash out the tanks. Extra pipes for future use have been built into the tank and gate chamber.

The flow from the gate chamber into the main carrier is also regulated by means of iron gates like the above. The gates are raised or lowered by means of chains, which pass over pulleys and through the wall of the tank, and are worked inside the tank house. The solid matter which settles in the tanks is discharged on to the sludge bed through the sludge pipe, as shown in Figs. 93 and 96.

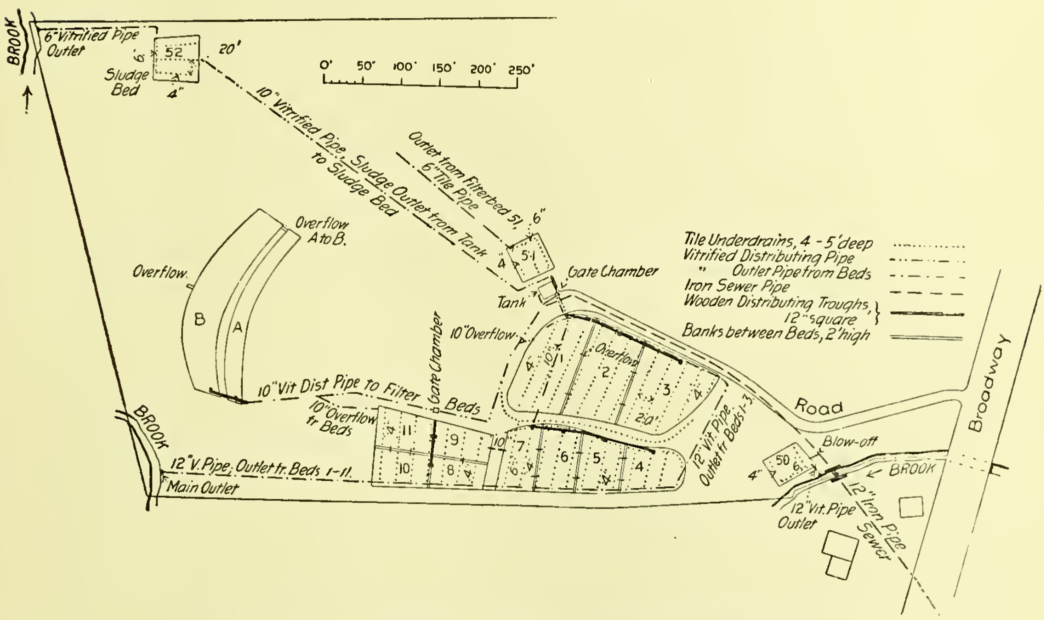


FIG. 96.—PLAN OF FILTER AREAS, GARDNER, MASSACHUSETTS.

In constructing the filter beds the surface was first levelled, the surplus dirt being used to make the banks, and the bottoms of most of the beds being formed in clay. They were then covered in gravel to the depth of from 4 to 5 feet, carted on from a bank south of the settling tank, after which the outlets for the effluent and the tile drains leading into them were laid. Then the banks subdividing the beds were built. The bottoms of these banks extend 1 foot below the surface of the beds. All of the banks were then sodded. The 10-inch distributing pipes were then laid and connected with square wooden troughs, firmly fastened to cedar posts set in the edge of the bed. These troughs are covered, but every other cover is hinged, so that the interior of the troughs can be examined at will. The troughs have

an opening at each bed, and by means of a board sliding in grooves the sewage can be directed on any bed, as desired. These troughs are from $2\frac{1}{2}$ to 3 feet above the beds, and the sewage falls on to a piece of stone pavement which prevents the washing of the beds. The tile drains are from 4 to 5 feet deep and 20 feet apart, and the banks are 2 feet higher than the surface of the beds. The surfaces of the beds are level. Beds A and B were constructed by simply levelling the bottom and building the banks. No tile or outlet pipe was laid, and the effluent simply soaked through the ground. An examination of the plan of the filter beds, Fig. 96, will show clearly their general arrangement. All of the beds except No. 51 discharge their effluent directly into the brook. The effluent from No. 51 is discharged into the woods, and is allowed to flow over the ground. The effluent is practically colorless and odorless, and has caused no trouble in the brook.

Overflows have been built, so that the sewage cannot flow over the banks in any case. Very little trouble has been caused by the extreme cold weather, as the sewage finds its way under the snow and ice and is filtered through the gravel. The road from Broadway was built and the hill graded, greatly improving the general appearance of the field.

The areas of the several beds are as follows:

No. of bed.	Area, sq. ft.	No. of bed.	Area, sq. ft.	No. of bed.	Area, sq. ft.	No. of bed.	Area, sq. ft.
1	9,520	5	4,300	9	3,240	51	2,300
2	8,570	6	4,400	10	3,850	52	3,370
3	8,790	7	4,000	11	3,850	A	5,000
4	4,400	8	3,240	50	2,500	B	11,000

Total, 82,330 square feet, or nearly two acres.

The above area does not include the space occupied by the main banks, but does include the division banks, the bottoms of which are only 1 foot below the surface of the beds.

Bed No. 51, Fig 96, was at first used as a sludge bed, but the odor arising from the sludge while drying, as well as from that which had previously been taken off and piled up near the bed, led to this bed being converted into a filter bed and the construction of bed No. 52 for a sludge bed. Since this change no trouble has been caused by the odor, as this bed is farther away, and is over the brow of a hill and surrounded by woods. No trouble has been caused by the filter beds, as there is no odor arising from them that can be detected a few feet away.

The sludge is allowed to remain on the sludge bed until it is dry, when it is removed and placed in piles and covered with dirt. The sludge is discharged from the tank, and the filter beds are cleaned

every two to three weeks. The sewage is discharged on to the filter beds in the following order:

First day.

Bed No. 1, from	7 A.M. to 10 A.M.
" " 2, "	10 A.M. to 1 P.M.
" " 3, "	1 P.M. to 5 P.M.
" " 4, "	5 P.M. to 7 P.M.
" " A and 5, from	7 P.M. to 7 A.M.

Second day.

Bed No. 6, from	7 A.M. to 9 A.M.
" " 7, "	9 A.M. to 11 A.M.
" " 8, "	11 A.M. to 1 P.M.
" " 9, "	1 P.M. to 3 P.M.
" " 10, "	3 P.M. to 5 P.M.
" " 11, "	5 P.M. to 7 P.M.
" " 51 and B, from	7 P.M. to 7 A.M.

This has been found to give satisfactory results.

The cost of the filter beds and accessories, not including engineering and superintendence, is stated to have been as follows:

Labor		$8,766
Vitrified pipe	$684	
Tile pipe	238	
Wooden troughs	305	
Total cost of carriers and drains		1,227
Carting		26
Freight		13
Wood dams at Beds A and B		13
Iron gates and gate chamber		99
Tank		600
Tank house		344
Miscellaneous		105
Total		$11,193

The cost of preparing the beds, with piping, was $10,046, or 12 cents per square foot, the area being 82,330 square feet. The total cost of the beds, tanks, and all accessories, was 14 cents per square foot of filtering area.

The general pipe system in place cost $40,530, including $1,719 for the 1,050 feet of iron pipe in the outlet sewer, making the total cost of the system $51,723, not including engineering and superintendence.

CHAPTER XLI.

INTERMITTENT FILTRATION AT SUMMIT, NEW JERSEY.

A SEWAGE system was built at Summit, New Jersey, in 1892, with C. Ph. Bassett, M. Am. Soc. C.E., as engineer. The natural outlet was to the Passaic river, but before discharging the sewage into the river it was deemed best to purify it by means of intermittent filtration. The filtration area was put in operation on August 2, 1892.

In November, 1892, there were nine miles of separate sewers, 20 flush-tanks, and 180 house connections.*

The filter beds are located about a mile from the village, within the township limits. One end of the disposal area borders on the Passaic river, as shown in the plan, Fig. 97. The township owns 26 acres of land, only 10 acres of which have been laid out in beds. Deducting the area occupied by embankments and a road, there are about eight acres of land available for filtration. There are only a few houses in the vicinity, and those are at some distance from the beds.

A public road passes through the disposal area. The land on the side of the road nearest the river slopes toward the river, and the beds are laid out in terraces, as shown by Fig. 98, which is a reproduction of a photograph taken near the lower edge of the tract. The beds are separated by earth embankments. The lowest beds are some 20 feet above the river. The effluent is discharged at the top of the abrupt river bank, and finds its way down the bank into the river.

Mr. Baker visited the beds on Nov. 28, 1892, and found the effluent with only a slight cloudiness and but very faint musty odor. The river showed no sign of pollution, and there was nothing about the disposal area which indicated to smell or by offence to sight the use to which it was put, except on raising a man-hole cover, when a very slight odor was observed.

Regarding the care of the beds, the attendant stated that their surface was raked up occasionally. He also stated that no fixed rule was observed as to the length of application of sewage to the beds, judgment being used in that respect.

The general arrangement of the beds, sewage carriers, outlet chambers, man-holes, sub and main underdains, and tile man-holes to give

* This description of the filtrstion area ia condensed from Eng. News, vol. xxviii., pp. 544–546 (Dec. 8, 1892).

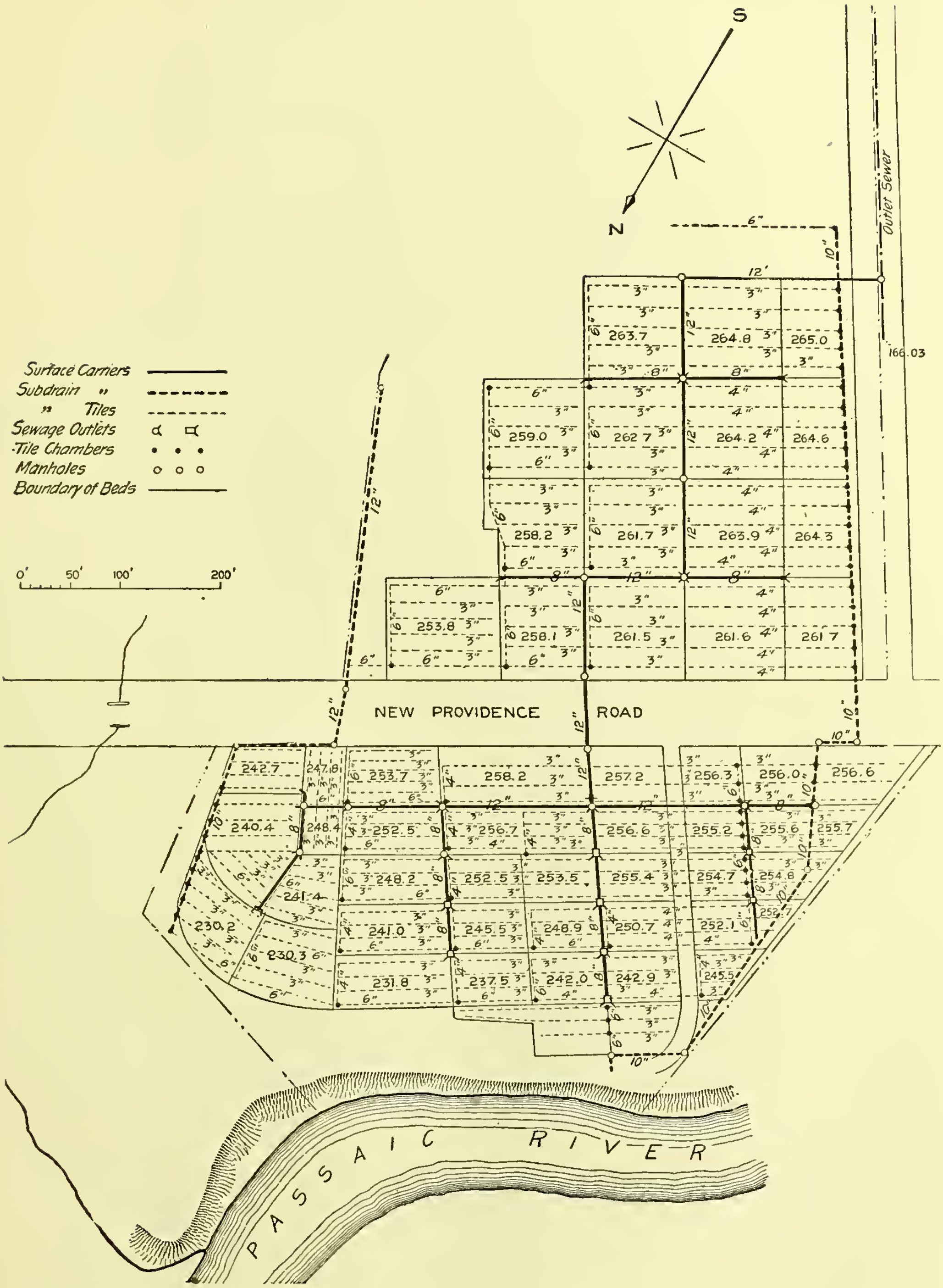


FIG. 97.—PLAN OF FILTER AREAS AT SUMMIT, NEW JERSEY.

access to the latter, will be seen by reference to the plan and the accompanying explanatory symbols, Fig. 97. The underdrains are placed with their centres at a depth of 3 feet below the surface of the beds.

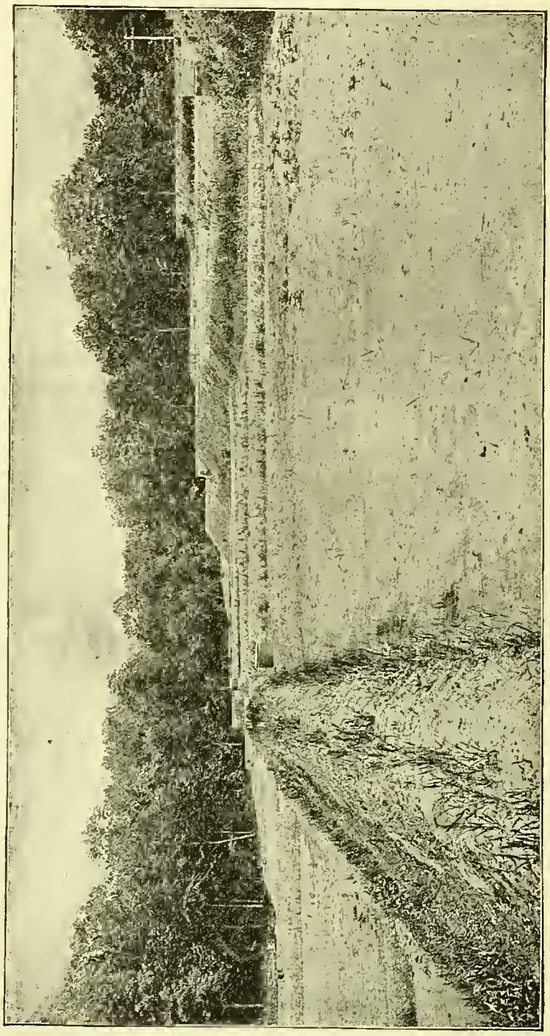
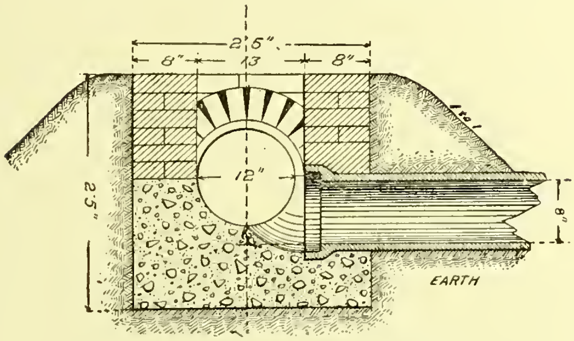
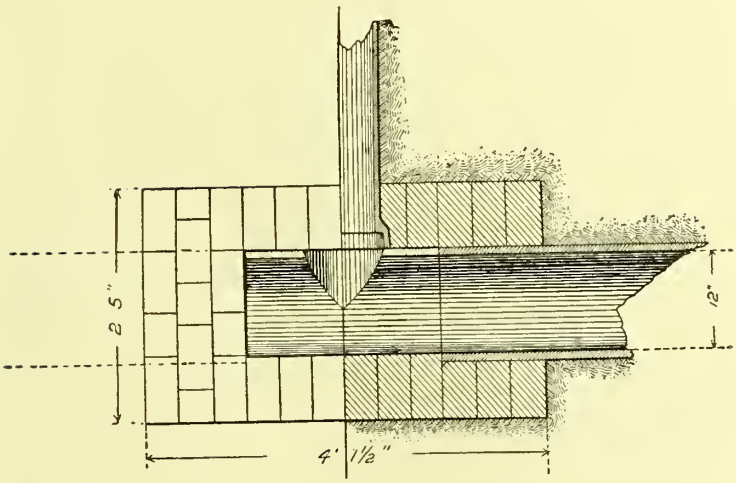


FIG. 98.—VIEW OF SUMMIT FILTER AREAS, FROM ROAD NEAR NORTHWEST CORNER.

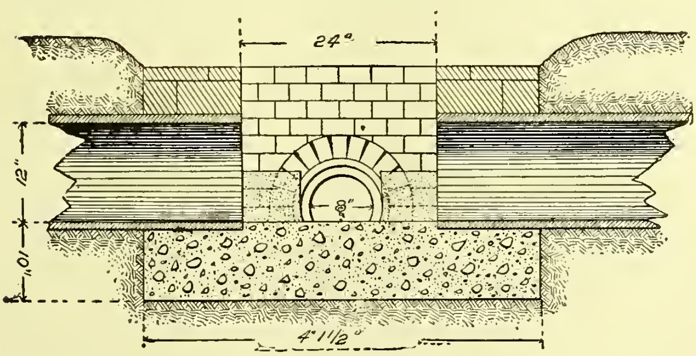
The sewage is distributed to the beds through pipe carried in the tops of the embankments, from which it is drawn through chambers and short lengths of pipe at the corners of the beds, all located as shown in the plan, Fig. 97. The details of the main carrier and branches, including the plugs used to divert the sewage as may be



CROSS SECTION THROUGH BRANCH.



PLAN AND HORIZONTAL SECTION.



LONGITUDINAL SECTION.

FIG. 99.—DETAILS OF SEWAGE CARRIER.

desired, are shown by Figs. 99 and 100. Where the beds to be served are at a lower level than the outlet chambers, half-tile, flat stone, and V-shaped troughs are used to carry the sewage down or to protect the embankment. All the brick chambers and manholes are lined inside and plastered outside with cement, and the brick manholes and some or all of the outlet chambers have board covers, painted.

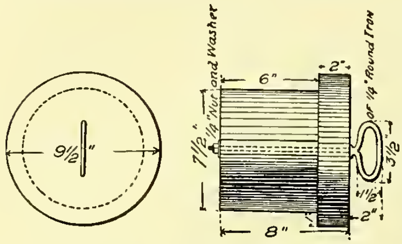


Fig. 100.—Plan and Elevation of Plug for Carrier.

At the intersection of sub and main underdrains tile chambers are placed, as shown in plan and section by Figs. 101 and 102. Fig. 102

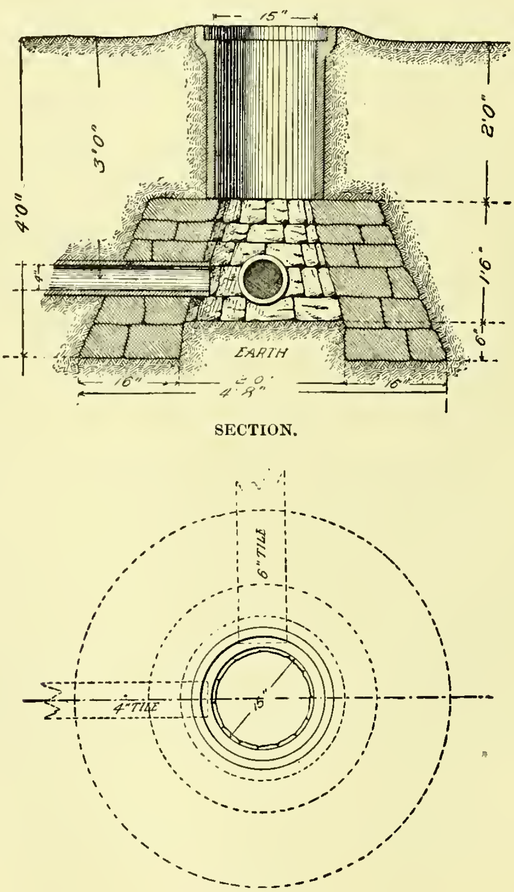


Fig. 101.—Plan and Section through Tile Chamber.

shows the underdrains at changes of grade at embankments, where adjacent beds are on different levels. There are but two or three of the special sections, shown in Fig. 102, they being placed only at points

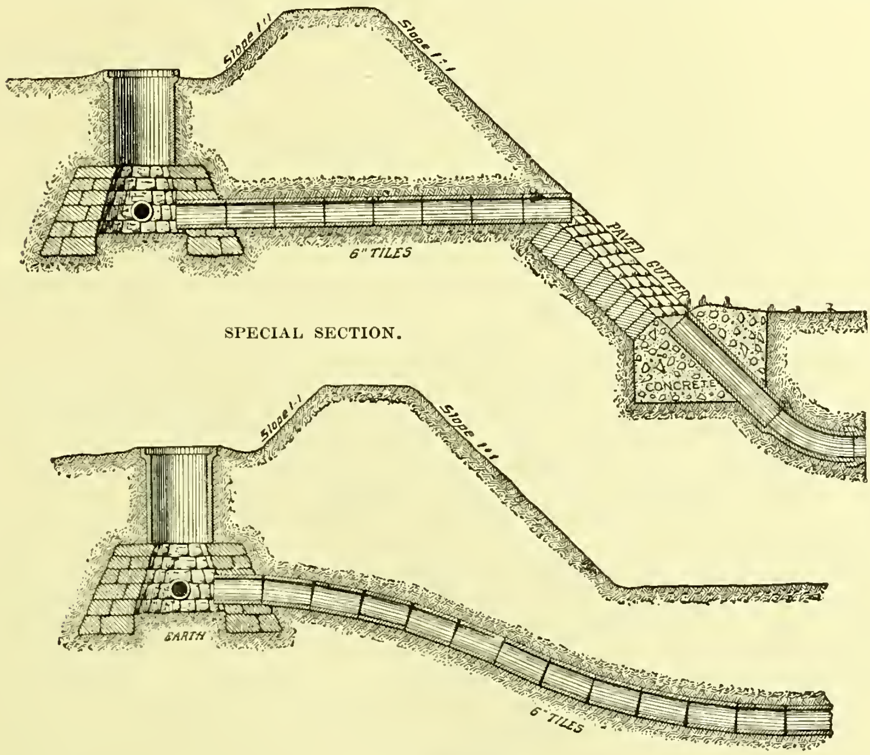


FIG. 102.—SECTIONS THROUGH TILE CHAMBERS AND UNDERDRAINS AT CHANGES OF GRADE AT EMBANKMENTS.

where the underdrain beneath a bed is at least 2 feet higher than the surface of the bed below. The tile chambers have iron covers, as shown in Fig. 101.

The effect of snow upon these filter beds during the winter of 1892–3 is referred to in Chapter XIV., p. 285.

CHAPTER XLII.

LAND DISPOSAL AT HASTINGS, NEBRASKA.

THE following description of the sewage purification plant at Hastings, Nebraska, where intermittent filtration has been practised for two years, and, as designed, will be combined with sewage farming, was prepared by the engineer of the sewerage and sewage disposal systems, Mr. J. M. Wilson, of Omaha, Nebraska.*

Hastings, Neb., is a thriving young city of some 15,000 (13,584 in 1890) inhabitants, situated on the plateau between the Platte river and the Republican. The Platte, about 16 miles to the north, is a broad, shallow stream, carrying in the spring and early summer a large volume of water from the melting snows in the mountains of Colorado and Wyoming; but in the late summer and winter the stream is largely lost in the sands of its many broad channels.

The Blue, a tributary of the Kansas river, about ten miles to the south, is a much smaller stream, but, being confined to a narrower channel, is more permanent in its flow.

These were the nearest and the only streams that could possibly be used for the discharge of sewage. Higher lands to the north cut off the outlet to the Platte. To reach the Blue would require that the line should follow the windings of some of the draws or valleys leading from the vicinity of Hastings to that river. This would so lengthen the line and increase the cost that all thought of reaching a running stream with the sewage was abandoned.

The only available method of disposal was a sewage farm. Upon investigation, the conditions at Hastings were found to be very favorable for the success of such a plant. Below the surface no water is found until a depth of about 100 feet is reached, at which depth permanent water is found in sand and gravel. The subsoil here is quite pervious to moisture; after the heaviest rains the water disappears quickly from the surface, being absorbed by the 100 feet or more of porous subsoil, without producing that condition of complete saturation which is so often found where the underlying strata are impervious or the permanent water level is near the surface.

In many cases, in the lands which must of necessity be selected for sewage farms, these favorable conditions do not exist, and only a few feet of the upper strata can be made available by artificial drainage. The amount of sewage that such lands will absorb without saturation is, of course, very limited, and the condition of permanent moisture so near the surface gives, by capillary attraction, all the moisture in most cases that crops grown on the land can appropriate. The additional moisture supplied by the sewage is just so much excess. The result is that on most sewage farms where crops are raised, very little of the sewage is applied to the crops, or only such crops are raised as will endure excessive moisture. The profitable crops that will endure such conditions are very few indeed. On the contrary, in this plains region, with its great depth of porous subsoil and its moderate rainfall, the conditions for disposing of sewage successfully, either by discharging it intermittently on limited areas or by applying it to crops, were peculiarly favorable.

The general surface of this part of Nebraska is a gently undulating plain, rising

* Condensed from Eng. News, vol. xxix. (March 9, 1893), pp. 218–20.

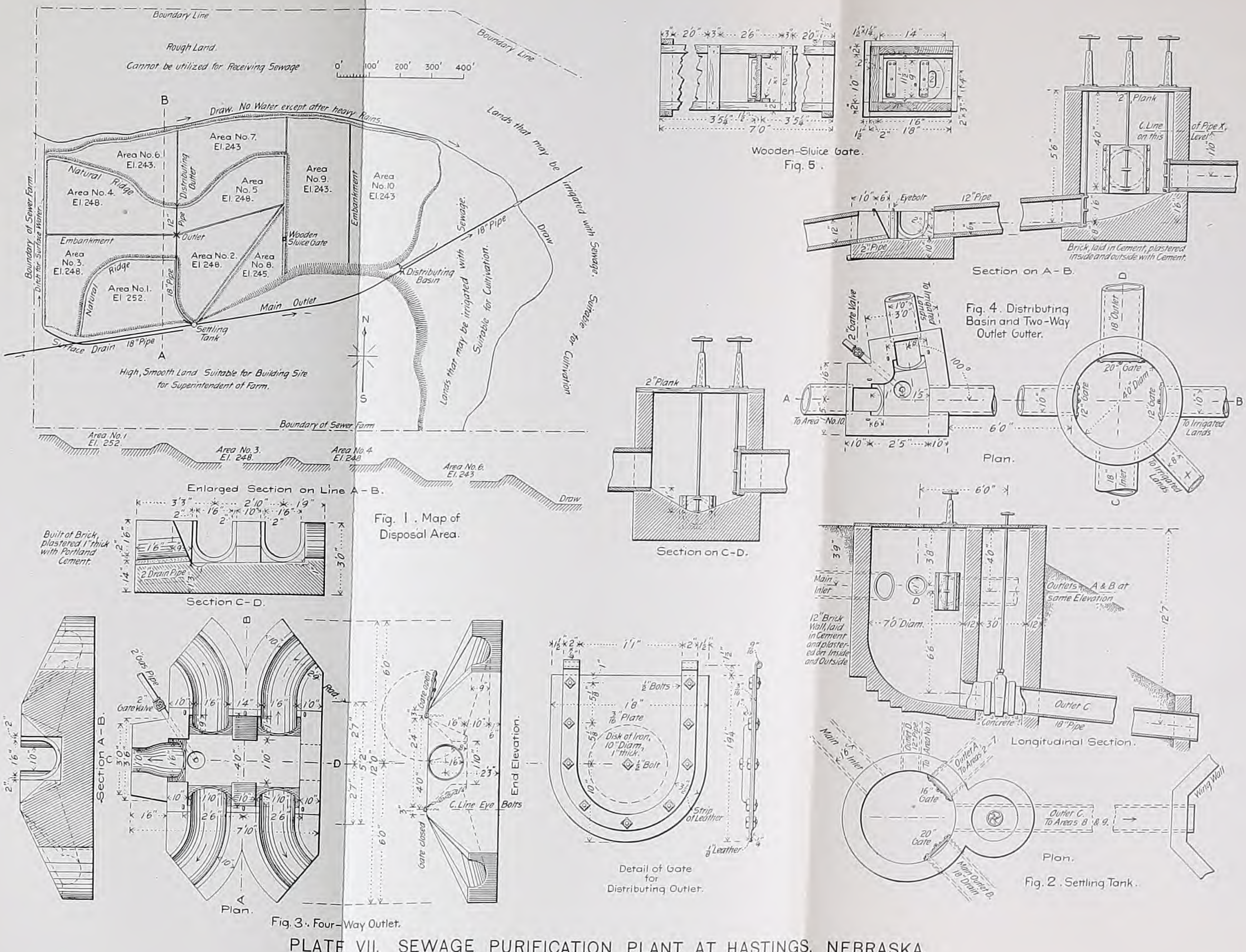


PLATE VII. SEWAGE PURIFICATION PLANT AT HASTINGS, NEBRASKA.

to the westward at the rate of say 7 to 10 feet per mile. In the vicinity of Hastings the rate is 9 feet per mile. The plain is broken by draws or valleys, down which the water passes to the permanent streams when there is any surplus. After heavy rains the draws are, for a few hours, quite respectable creeks; but ordinarily they are dry, and the surface, where it has not been disturbed by the plough, is covered with a thick, strong sod. Along the sides of these draws the land has been lowered by the action of the water considerably below the general level of the surrounding plain, and yet left high enough above the bottom of the draw to insure adequate drainage.

With a pumping plant that would raise the sewage 15 feet, any one of the many smooth farms lying to the east was available for a sewage farm, practically graded and ready for the reception of the sewage. The objections to this arrangement were:

(1) The cost of erecting and maintaining the pumping plant; and (2) the difficulty that might arise in draining such a tract in case, as was likely, it should need drainage after the sewage was applied.

If the sewage was to be disposed of by gravity, the only available fields were the lands before mentioned, lying adjacent to the draws. These were somewhat irregular in outline and elevation, and would require considerable grading to put them in shape for the application of the sewage; but they were so situated that good surface drainage was insured, and if it should become necessary to tile the farm later, the draw would afford a ready outlet for such drainage.

A small draw, heading in the northeast corner of the city, leads off toward the northeast about 1½ miles, where it intersects with a much larger draw from the northwest. Along the borders of this larger draw there are considerable areas which, while elevated enough above the bottom of the draws for drainage, are low enough to make it possible, by careful economy in grades, to reach them by gravity from every part of the city. It was found that the storm water could be sent off through the natural waterways by using short runs of large pipe at moderate depths, and with better fall than it was possible to secure for the sewer line to the farm.

This, with the limited areas available for receiving the sewage and the difficulty of taking care of the storm water on such a farm, settled the question in favor of the separate system of sewerage.

The nearest land available for a disposal area was a tract of 70 acres, somewhat broken. To find smoother land upon which the sewage could be deposited by gravity would have necessitated a lengthening of the main pipe from 3,000 to 5,000 feet and the crossing of several small draws. The additional cost of this part of the line would have more than overbalanced the necessary expense of grading, not to mention the extra cost of caring for and maintaining the additional line.

The 70-acre tract selected for the sewer farm is shown by Fig. 1, Plate VII. The southwest part of the tract is too much elevated to receive sewage, but is valuable farming land and will furnish a desirable building site for the residence of a superintendent.

The northwest portion of the area north of the draw is very rough and cannot be utilized for sewage, except at heavy expense for grading and piping. The central part of the western half of the area has been graded into areas, as shown on the map, each having its own level and separated from the adjacent areas by a low ridge of earth. The cross section at the foot of Fig. 1, Plate VII., shows the arrangement of these ridges and slopes. The elevations selected and the forms of these areas were determined largely by the question of economy in moving the earth.

These areas were brought to a uniform grade, except at the points where the sewage is received from the distributing gutters. Here the surface was slightly elevated, to secure a better distribution over the surface when the sewage is first discharged on an area. The sewage is discharged first into a settling tank, shown in plan and section by Fig. 2, Plate VII.

This tank is provided with cast-iron gates for controlling the flow of the sewage. It was the intention to provide a screen, but is was found that it was not necessary, as the paper and the small amount of solids which would make trouble by clogging the drains were all deposited in the lower part of this tank, from which it could be

drawn off on the lower area, No. 8, where it could be readily collected and disposed of when the water was drained out of it.

From this settling tank the sewage is conducted to distributing or outlet gutters, so situated as to distribute the sewage on two or more adjacent areas. These gutters are built of brick laid in cement mortar and plastered with Portland cement, as shown by Figs. 3 and 4, Plate VII. The gates which regulate the flow are of $\frac{3}{16}$-inch plate iron, faced with sole leather and set at an angle from the vertical, so that their weight, which is increased by a heavy cast-iron disk bolted to the back, acts with the sewage to shut the gate snugly against the seat. The seating face is 2 inches wide and built up of cement. The gate is opened by revolving it upward and backward till it rests on the top of the gutter.

Areas Nos. 1 and 8 receive sewage from short lines of pipe leading from the settling tank, as shown by Figs. 1 and 2, Plate VII. Areas Nos. 2, 3, 4, and 5 are supplied by an 18-inch pipe from the settling tank, the sewage being distributed to each of the four beds by the four-way gutters shown in Fig. 3. A 12-inch continuation of the 18-inch pipe from the settling tank carries the sewage to areas Nos. 6 and 7, the two-way outlet gutter here being similar to that shown in Fig. 4. An ordinary wooden sluice gate is the only means provided for supplying sewage to area No. 9. This gate is shown in plan and section by Fig. 5, Plate VII. Area No. 10 is supplied by one of the branches of the two-way gutter shown in Fig. 4. The other branch of this two-way gutter is designed to discharge sewage on to a part of the irrigable land nearest to the distributing basin, the remaining part of this section being provided for by the 8- and 12-inch outlets on the south side of the basin, all as shown in the plan, Fig. 1. The 18-inch main outlet is extended across the draw to the most distant part of the disposal area, this section being suitable for irrigation.

The farm is under the care of a superintendent of sewers and water-works. He visits the farm once a day, or as often as may be necessary to change the flow from one area to another. The time of discharge on any given area is determined largely by the season and the amount of rainfall, and must be regulated by the experience and intelligence of the superintendent. Occasionally the areas are ploughed to facilitate absorption and to cover up deposits, which, with the carting away at intervals of the sludge discharged from the settling tank, is all the attention the farm receives.

The works have now been in operation about two years. The first year was an unusually wet season, and the capacity of the soil for receiving sewage was for this reason much reduced, but it was all discharged in rotation upon the areas that had been graded. No offensive odors were perceptible from the fields, as everything was distributed before decomposition set in, and the sewage was not allowed to discharge or remain on one area long enough to become putrid. The only time when any odor is perceived is when the settling tank is opened to discharge the collected solid matter. At such times for a short interval there is a little odor when the discharge is first made ; but it is only perceived in its immediate proximity.

Up to Jan. 1, 1893, the number of sewer connections that had been made was 119, mostly from the business part of the city and the larger residences. Outside of the business portion no attempt has been made to compel the making of connections.

The lands marked on the plan as suitable for irrigation cultivation are all available for absorption fields ; and if a larger area is needed, the lands along the valley to the eastward will afford opportunity for increasing the areas to any extent desired. By means of shallow ditches and furrows along the slopes, the sewage may be conducted over these lands and used for irrigating crops, as with the water from irrigating canals in the arid regions of the West. No attempt as yet has been made to use it in this way, but at intervals the sewage is allowed to flow over the meadow land of this portion, as far as it can do so without special direction and yet not escape into the draw.

The absorption areas now in use are not underdrained, but depend entirely upon the capacity of their soil for absorption. Ultimately tiling will be necessary, and this will convert them into filtering beds discharging their effluent into the draw. When the farm was first put in use it had been freshly graded, and it was not

thought best to put in tile until all settlement of the fills had ceased. We also wished to test the capacity of these areas without the tiling. With the amount of sewage now disposed of the results are satisfactory, but I have no doubt that in time they will all require drainage.

In arranging this farm, while keeping in view the desirability and the possibility of using the sewage in the cultivation of crops and arranging for its use when the quantity of sewage would make such use profitable, these two facts have been kept steadily in mind: (1) That with all crops of value, the amount of sewage that can be used with profit has very definite limits; (2) that the time during which it can be applied to any crop is ordinarily confined to only a limited portion of the growing season. To apply in greater quantities and at other times is to ruin the crop.

CHAPTER XLIII.

SURFACE IRRIGATION AT WAYNE, PENNSYLVANIA.*

WAYNE is a surburban residence village about 15 miles from Philadelphia, on the Pennsylvania Railroad. It has been built up by Messrs. A. J. Drexel and Geo. W. Childs, who bought the Wayne estate some years ago. In June, 1890, its population was 997. Two years later a population of 2,000 was claimed. There are no manufactories.

Water-works were built by Drexel & Childs in 1881. Shortly after, Col. Geo. E. Waring, Jr., M. Inst. C.E., was engaged to extend the sewerage system of the village, which then conveyed the wastes and roof water of a few buildings into a brook flowing through the valley.

Col. Waring extended the system on the strictly separate plan, collecting the sewage in a large flush tank, from which it was discharged into the brook through an 8-inch pipe 2,925 feet long, having a fall of 1 foot in 400. An additional area being secured later, a 12-inch outlet was laid parallel to the lower part of the first outlet.

The brook which received the sewage had a copious flow and discharged into Darby creek, a stream polluted by manufactories. The brook gradually became fouled, to prevent which the sewage was finally delivered into a settling basin before passing to the brook. The effluent not being sufficiently cleared by this settlement, it was discharged into a second, and later into a third settling basin.

The farm land along the brook gradually being taken up for residences, complaints regarding the fouling of the stream increased, and finally an injunction to prevent the discharge of sewage into the brook was threatened. When the works described below were recommended by Col. Waring, in the spring of 1891, the move for an injunction was stopped under verbal protest.

Surface irrigation on somewhat isolated land at the lower side of the estate was decided upon. The disposal area is thus described by Col. Waring in an article in the of *American Architect* July 2, 1892, from which much of this information has been taken:

The tract to be used was of unfavorable character, but it was the only one available. It consisted mainly of an old pond surrounded by ancient pollard willows, a large area of swamp through which the brook meandered, about four acres of slightly sloping cleared land, and a very steep, thickly wooded and rocky hillside,

* Condensed from Eng. News, vol. xxviii., pp. 422–4 (Nov. 3, 1892).

rising about 100 feet from the level of the brook to one corner of the nearly square tract.

The pond was obliterated, the willows and much other vegetation were cleared away, the brook was confined within stone walls, and all except the steep hillside was thoroughly underdrained.

The disposal area includes eleven acres, divided by the creek as shown in Fig. 103. Along the lower course of the brook much of the

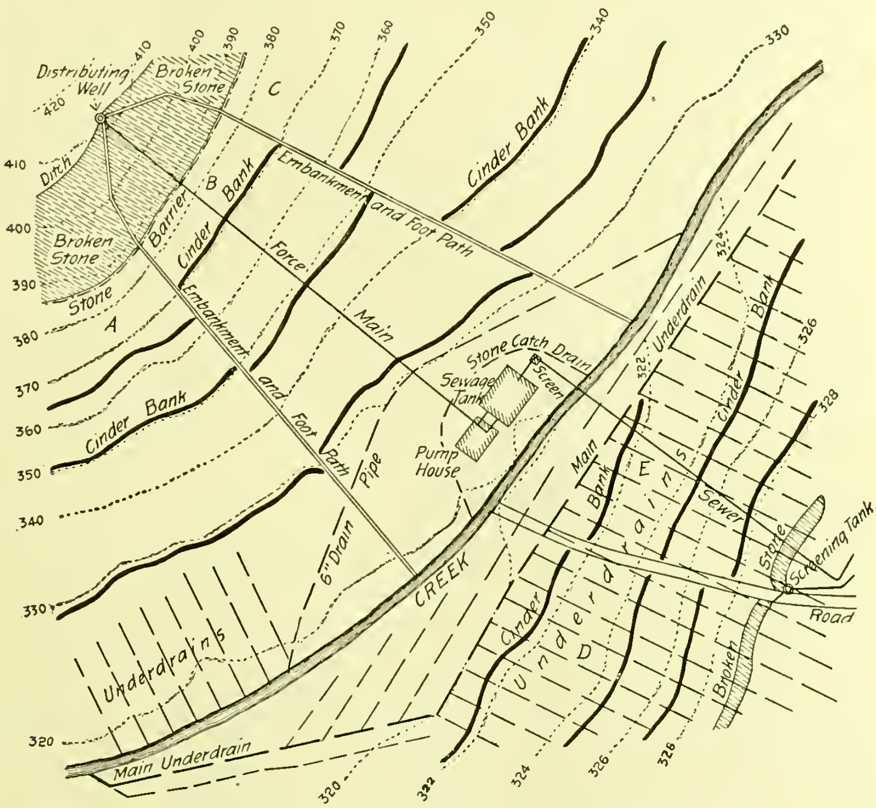


FIG. 103.—PLAN OF DISPOSAL WORKS, WAYNE, PENNSYLVANIA.

land was a nearly level tussock swamp. All growth less than eight inches in diameter was removed from the tract. The creek was straightened and deepened, and the banks sloped back from the walls of the creek and sodded. But little grading was necessary on the left or south side of the creek, but the whole area on the other side was graded. The header drain of six-inch pipe on the left side of the creek was laid to cut off the effluent from some slightly wet land. The stone drain is for the protection of the pumping station.

The land on the south side of the creek was divided into three nearly

equal tracts by embankments about one foot high, which converge at the distributing well. A road to the pumping station divides the land on the north side of the creek into two sections.

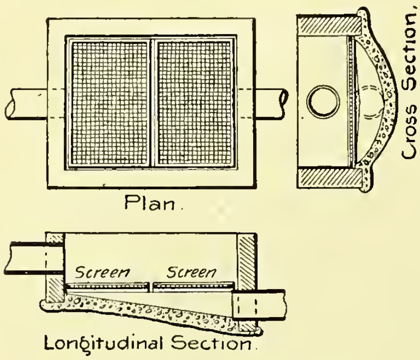


FIG. 104.—SCREENING CHAMBER.

The outlet sewers already described were intercepted just above the old settling basins, from which point a 12-inch vitrified pipe, with a fall of 1 in 125, extends to the edge of the disposal field. About 400 feet above the edge of the field an 8-inch branch, with a fall of 1 in 250, extends to a screening chamber. From this chamber the sewage is delivered at will on to tract D or E, first passing over a bed of broken stone.

The main outlet sewer is of vitrified pipe where in earth, and of iron and cement where on piers. It ends in a brick screening chamber with a concrete bottom near the pumping station, shown in plan and

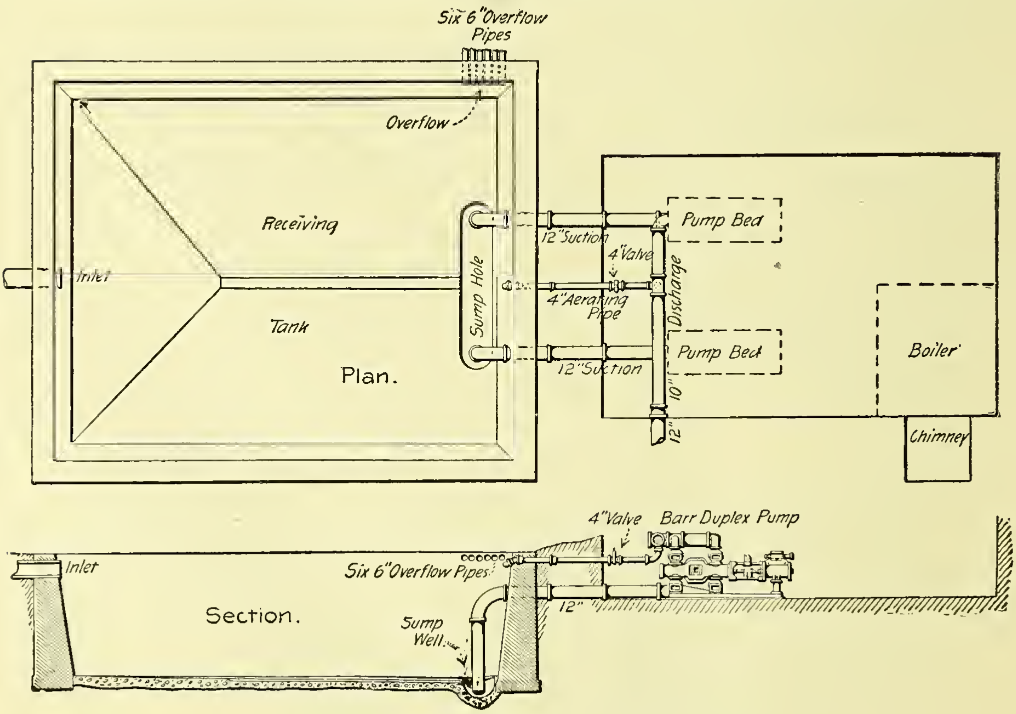


FIG. 105.—RECEIVING TANK AND PUMP HOUSE.

section by Fig. 104. After passing through the screens the sewage flows into the receiving reservoir, shown in plan and longitudinal section by Fig. 105. This reservoir has a capacity of 90,000 gallons to the mouth of the inlet pipe. Its bottom is of concrete and slopes toward the sump into which the suction pipes extend. Six 6-inch pipes at the top of the tank lead to the creek as an overflow.

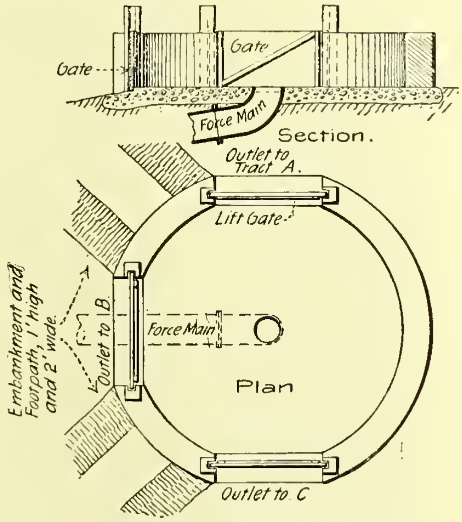


FIG. 106.—DISTRIBUTING WELL.

Two Barr duplex pumps, with a capacity of about 22,000 gallons each per hour, or 525,000 gallons per day, force the sewage up the hill on the left of the creek to the distributing well. This 12-inch force main is of spiral weld steel pipe, is 480 feet long, and has a rise of about 100 feet. The lower end of the force main was placed above ground, to obtain a grade that would allow it to drain dry through the aërating pipe, mentioned below.

Both pumps are started when the screening reservoir is nearly full, and, as designed, the sewage is first delivered back into the receiving tank through a 4-inch aërating pipe, the object being to deodorize the sewage and increase its oxygen. Aëration is maintained for from 60 to 90 minutes, after which the valve in the aërating pipe is closed and the sewage is delivered into the well.

The distributing well is shown in plan and section by Fig. 106. It is of brick with a concrete bottom, and is covered by a small building shown in the distance in the view, Fig. 108. Lift gates, working in the masonry of the well, are provided to regulate the discharge of the sewage upon the tracts.

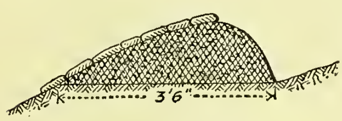


FIG. 107.—CROSS SECTION THROUGH CINDER BANK.

A bed of broken stone, about 8 inches deep and 50 feet wide, extends across the tract below the distributing well. Sewage is discharged into a depression along the upper edge of the stone bed. When this depression is filled the sewage flows down the bed, which has a fall of about 1 to 4, to a catch wall of broken stone designed to check the somewhat rapid flow of the sewage and to distribute it evenly over the land below.

The cinder banks shown in Fig. 107 are laid on graded strips follow-

ing contours. The cinders, mostly from locomotives, are backed, to prevent washing. These banks are designed to catch the sewage in its irregular flow down the steep hillside and start it again uniformly.

The receiving reservoir fills in from 6 to 12 hours, and is emptied in

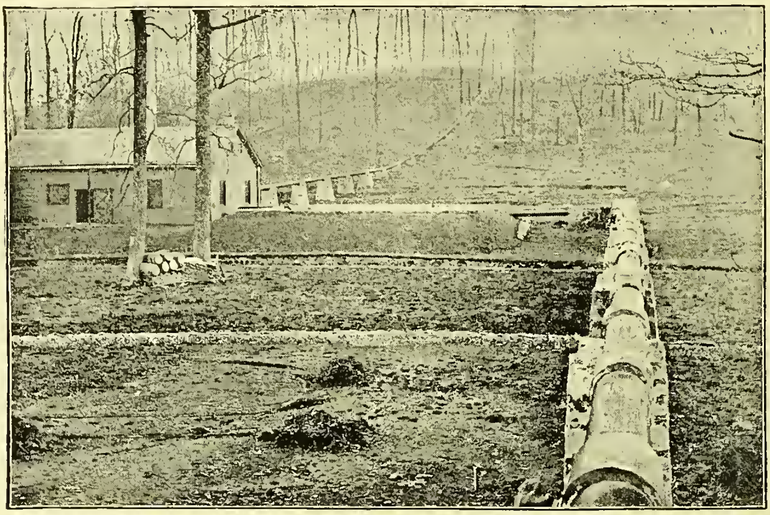


FIG. 108.—GENERAL VIEW OF WAYNE DISPOSAL WORKS, FROM NORTH SIDE OF CREEK.

about 5 hours. The sewage disappears from the surface of the land in about a half-hour after the pumps are stopped.

The field on the left side of the creek was put in operation in September, 1891. The field at the right of the creek was put in use later, before well covered with vegetation. Col. Waring states that if the aëration of the sewage, as described above, proves sufficiently beneficial, a force main will be constructed to the field at the right, and sewage delivered to it by pumping, instead of by gravity, as now.

Figs. 108 and 109 present views of the disposal works from two different points.

Oct. 27, 1892, Mr. Baker visited the Wayne purification works, and through the courtesy of Mr. Frank Smith, manager of the Wayne estate, and Mr. C. D. Slaw, superintendent of the sewerage system, obtained the additional information which follows.

There are now about 600 acres in the estate. All buildings on the property are connected with the sewerage system, there being about 275 connections. The average daily consumption of water in Wayne is stated to be about 200,000 gallons. The average sewage pumpage was given as about the same, but from all the data at hand it would

seem to be higher. Two days out of five, according to the information given, the sewage flows by gravity on to the north part of the area.

The first screens used at the screening chamber at the receiving reservoir had a 2-inch mesh. This mesh proved to be too coarse, and screens with 1-inch mesh are now used. The rakings from the screens average about two barrels a day, there being more on Saturday, Sunday, and Monday than on other days. Lime is put upon the rakings as they accumulate beside the chamber before removal.

The pumping station is kept open throughout the 24 hours, and the pumps are run from 16 to 18 hours a day, requiring about 110 pounds of buckwheat coal per hour. Two engineers are employed at the station, and the superintendent divides his time between it and the part of the sewerage system within the village. In addition, laborers are employed when necessary, which, it would seem, is not often. Sewage is turned upon each tract for only one day at a time, so that each tract has a rest of five days.

The material in the barriers has never been changed, and the

FIG. 109.—GENERAL VIEW OF WORKS FROM SOUTH SIDE OF CREEK.

broken stone at the top of the hill on the south side of the creek, Mr. Slaw stated, has never been cleaned, except that one section has had one cleaning. The broken stone at the head of the areas on both sides of the creek showed only a small amount of rags and paper which had been caught. At the dam of broken stone at the top of the steep hillside, and at the first barrier below, sludge accumulates and has to be

shovelled out. Except at the first or stone barrier, the sewage rarely runs over the top of the banks, unless they are stopped by leaves, as is likely to be the case in the fall of the year. The sewage has a tendency in the first part of its course to run down the steep hillside in channels, and to some extent this has been encouraged, or rather several small channels have been formed in order to keep the sewage from flowing down in one large one.

There was scarcely any trouble from frost during the winter of 1891–2, and that at only one corner of the field.

As the sewage came from the middle gate of the distributing well at the top of the hill it was cloudy, and like any sewage not affected by manufacturing wastes. At the second barrier, counting the dam of broken stone as one, little change was noticed, perhaps because the sewage came quite directly and rapidly from the first through two or three channels. At the third barrier the sewage was clearer, and a dog drank freely of it. Behind the fourth barrier a clear-looking liquid four or five inches deep was found. Below the last barrier no sewage could be seen. At Iphan creek, which flows through the grounds, there was evidence of some seepage through the walls of the creek below the section which was receiving sewage, but the seepage was slight and might have been natural. At the ends of the drain and trench of broken stone no effluent was discernible. The creek showed no signs of pollution by the effluent, and small fish were observed in it.

At least five crops of grass were raised on each side of the creek in 1892, and a man was engaged in raking up a fair crop of grass from the field north of the creek on the day of Mr. Baker's visit.

CHAPTER XLIV.

THE USE OF SEWAGE FOR IRRIGATION IN THE WEST.*

Considering the general development of the two sections of the country, the western part of the United States is about as far advanced in the purification of sewage as the eastern. This is accounted for in three ways : (1) The very low stage of western streams during the hot, dry season often renders sewage discharged into them an unbearable nuisance, or there may be no natural stream near by of sufficient size to receive sewage ; (2) the familiarity of the people with irrigation ; and (3) the value of all available water for this purpose naturally leads to the application of sewage to crops when any method of purification is necessary.

For the foregoing reasons all but two of the sewage purification plants west of the Mississippi river employ irrigation, and one of the two exceptions, Hastings, Nebraska, uses intermittent filtration and will probably raise crops eventually, while the other, Leadville, Colorado, only strains the sewage through a small area of sand.

As shown below, eight western towns are prepared to apply sewage to land for irrigation in the season of 1893. In addition, Los Angeles may also be ready to so dispose of its sewage in 1893, and until three years ago had been so doing for some time ; while at Cheyenne, Wyoming, sewage was for a period of seven or eight years delivered into an irrigating ditch and used for irrigation, this use being stopped only by a change in the outlet sewer.

Some of the leading points regarding these sewage farms are given in the accompanying table, from which it appears that sewage was first used for irrigation at Cheyenne, Wyoming, probably in 1883.

Colorado Springs, Colorado.

The population of this city increased from 4,226 in 1880 to 11,140 in 1890. Water-works were built in 1879 and a sewerage system in 1888. Sewage was first used for irrigation in 1889. January 1, 1893, there were in use 20.4 miles of separate sewers, 239 man-holes, 683 house connections, and 18 flush tanks.

A statement of the causes which led to the use of sewage for irriga-

*See Eng. News, vol. xxix., pp. 183–6 (Feb. 23, 1893).

GENERAL INFORMATION REGARDING THE USE OF SEWAGE FOR IRRIGATION IN THE WEST.

	Population, 1890.	Ready for use.	Irrigation adopted on account of—	Ownership of irrigated land.	Rental.	Crops raised or proposed to be raised.
Colorado Springs, Colo..........	11,140	1889 ..	Litigation on account of pollution	Private.	$300* per year, 5 years	Alfalfa, hay, garden truck.
Trinidad, Colo. ..	5,523	Fall, 1892..	To prevent pollution of water used for domestic purposes.	"	$500* "	Blue grass proposed.
Fresno, Cal......	10,818	Jan., 1890..	Best av'l'ble method	"	$5,000*	Chinese truck gardens.
Pasadena, Cal....	4,882	1893...	Evidently some purification necessary..	City....	....	B'rly, hay, fruit, veg't'bles proposed.
Redding, Cal	1,821	1888...	To prevent pollution Sacramento water supply........ ...	Private.	$300* first year,† and yearly increase.	Grain, potatoes, vegetables, fruit.
Los Angeles, Cal.	50,395	Prior 1887..	To provide water for irrigation.........	"	No rental formerly.‡	Miscellaneous.
Santa Rosa, Cal..	5,220	1889 or earlier	Litigation on account of pollution........	City....	Leased without rental.	Garden truck.
Helena, Mont....	13,834	1889...	Means of providing park	"	Leased: lessee to make improvements and cash payment.	Vegetables, nursery stock.
Cheyenne, Wyo..	11,690	Prob. 1883..	To provide water for irrigation..	Private.	No rental.	....
Stockton, Cal....	14,424	1892 or 1893..	To provide water for irrigation	"	....	....

* Paid by the city. † Increase yearly proportionately with assessment roll. ‡ City may exact a rental of $3 per acre for land covered by new outfall.

tion, and a description of the sewage farm, have been furnished by Mr. H. I. Reid, city engineer and engineer of the disposal plant, as follows:

In the utilization of sewage for irrigation purposes at Colorado Springs no attempt is made toward treatment or purification other than by natural means and in a rather primitive manner. The system was adopted as a compromise measure, to avoid suits for damages for the alleged pollution of the stream into which the outfall sewer originally emptied, "Fountain Qui Bouille," commonly known as Fountain creek. This stream has a normal flow at the sewer outlet of 50 cubic feet per second, but at times during the irrigating season this is reduced to almost nothing, although during the same season floods may be expected, when for a few hours or days the creek becomes a swift-flowing river, with a fall of 30 to 40 feet per mile.

The original sewerage system was put in operation in 1888. The following year a ranchman, living some two miles below the outlet point, shown in Fig. 110, instituted injunction proceedings to prevent the sewage from being turned into the stream, claiming that his well, situated near the stream, was so polluted as to render it unfit for drinking purposes, and that the water in his irrigating ditch, the head gate of which is $\frac{3}{4}$ mile below the sewer outlet, was so foul that stock would not drink it. Before the suit came to trial the city council appointed a committee to try and arbitrate the matter. This was done and the suit was withdrawn, the city paying all costs of proceedings to that

date, and agreeing to divert the sewage at some point on the outfall and utilize it for irrigation on the lands designated on the accompanying map, Fig. 110.

A contract was made between the city and the owner of this land, whereby the city was to deliver the sewage at the point B, Fig. 110, by the line A B, and to pay annually $300 for five years; the owner to receive the sewage at this point and use the same for irrigation purposes in such a manner as he deemed best, provided, however, that he prevent the sewage from flowing directly into the creek, and provided, further, that if the method of irrigation was not satisfactory to the ranchman bringing the suit, or to the city, then the city should have possession of the land and use such methods as it thought best. At the expiration of the contract the city has the option of buying the land at a stipulated sum, and probably will buy it, although there are now many parties who would pay for the sewage delivered to their land.

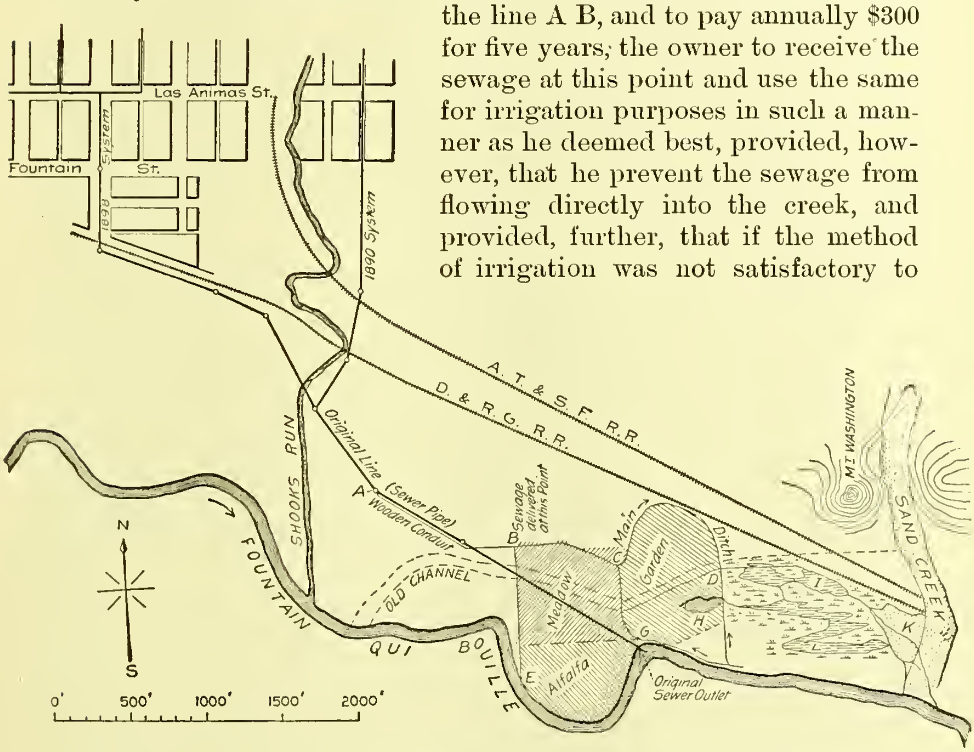


FIG. 110.—PLAN OF SEWAGE FARM AT COLORADO SPRINGS, COLORADO.

The city tapped the outfall at the point A, Fig. 110, and by means of an underground wooden conduit on a less gradient than the original outlet delivered sewage on the surface of the ground at the point B, whence the lessee takes charge of it and delivers it to grounds by the ditches B E and B C D, and thence by laterals to any desired point.

The map shows that many years ago the stream followed a different channel than the present one, the depression of which extends through the entire tract from west to east, and is from 3 to 4 feet lower than

the north bank of the creek at corresponding points at right angles thereto. The old channel is the medium whereby the surplus sewage is carried off without flowing directly into the creek.

The sewage is distributed by means of small ditches or furrows through the garden tract, whence all liquid matter not absorbed by the earth flows back into this old channel, and thence into the depressions, forming small reservoirs at H, I, L, Fig. 110. The small laterals radiating from the main ditch irrigate the northern portion of the lands, and in a similar manner any surplus flows into the same reservoirs. During the irrigation season, which in this instance is from March 1 to Nov. 1, there is but little surplus, the character of the soil being such that the greater portion is absorbed or carried off by underflow.

In constructing the outlet sewer, throughout this entire tract of valley land, from the surface to a depth of 2 or 3 feet, loose black loam was found, then a 2-foot stratum of sand, below which was coarse gravel and sand, through which water was flowing with considerable velocity, so that at a depth of 6 feet it was found necessary to dig a parallel and deeper trench to carry off the water, in order to facilitate pipe-laying. This probably explains the rapidity with which the sewage is absorbed when applied for irrigation. As soon as sufficiently dry, after each application of sewage, the soil is thoroughly pulverized and any accumulation of solid matter turned under before receiving another application.

When irrigation is not in progress the entire flow is carried through the main ditch and emptied into the old channel and depressions mentioned. The upper pools or reservoirs, Fig. 110, were ploughed out by the action of surface water; the lower or most easterly one is a reservoir, the dam of which was built up through a similar agency. Immediately north of the railway tracks are sand and gravel hills, some 200 feet higher than the valley and very steep. During the rainy season flood water flows into Fountain creek, across the valley at right angles to the old channel. At such times the débris brought down has been deposited upon the lower level of the valley, and a sand dike several hundred feet wide and 5 or 6 feet higher than the lowest portion of the valley has been formed, thus converting the valley at this point into the basin K, Fig. 110, the area of which is some three or four acres. All surplus sewage collects in this basin and rapidly seeps away into the underflow and finally into the creek. The solid matter is deposited in the basin, and that it will in time cement the bottom and fill it up is very probable; but no trouble of this kind has been experienced to this date, and to all appearances there is very little deposit of any kind. It is said that no unpleasant odor is experienced on any portion of the farm at any time.

So far as practical results are concerned the disposal area is sucessful, inasmuch as the city is relieved of costly litigation and also from the care and maintenance of the outlet lines. The lessee is well pleased because of the enormous crops raised and lack of trouble from the vexatious problem of "priority of water rights." As illustrating the demand for water in this section, it may be stated that the ranchmen several miles below the outlet, seeing the sewage farm well supplied with water at times when they have none, threaten to enjoin the city from using the sewage for this purpose, and to compel it to turn the sewage into the stream for their benefit.

The sewage farm comprises at present an area of about 35 acres, but may be added to as future needs require. In 1892 the sewage was used on 25 acres—15 in meadow and alfalfa and 10 acres in vegetables; but a larger acreage could be covered with the present amount of sewage. The crops produced are enormous, and owing to close proximity to the market the farm is a paying investment. As already stated, at present the city has nothing to do with the management of the farm, but the probabilities are that when the lease expires the city will buy the farm and enlarge the system.

Under date of Jan. 24, 1893, Mr. Reid wrote that he had recently visited the sewage farm, and found the sewage running directly into the creek through a ditch cut from the reservoirs, shown in Fig. 110. This, he states, is in direct conflict with the terms of the agreement, but that possibly it was done to flood the lands of ranchmen below, who have recently been willing to take all the sewage they can get.

Trinidad, Colorado.

The city of Trinidad is divided into two parts by the Las Animas river, a comparatively small stream during much of the year. The farmers below the city depend upon ditches leading from the river for water for domestic use, which makes some form of sewage purification especially necessary. Following the advice of Mr. Norval W. Wall, city engineer, it was decided to purify the sewage by irrigation. A contract was therefore made with Mr. Jas. M. John, who was mayor at the time, to receive and dispose of the sewage on land owned by him, the city paying $500 per year and delivering the sewage upon the land.

The population of Trinidad in 1880 was 2,226, in 1890 it was 5,523. A public water supply was introduced in 1879 by the Trinidad Water-Works Co. A sewerage system was put in operation in 1892, the outfall sewer having been completed about three months before the close of the year. Mr. Wall was engineer of the system.

On Jan. 1, 1893, there were in use two miles of separate sewers, 18

man-holes, two flush-tanks, and 12 house connections, mostly to public buildings.

An 18-inch vitrified outlet sewer 7,100 feet long leads from the city to the sewage farm. This outlet has a theoretical velocity, when running full, of 2.58 cubic feet per second.

At the farm end of the outlet there is a masonry settling tank 50 feet long, 5 feet wide, and 4 feet deep.

The sewage farm slopes toward the Las Animas river at the rate of from $2\frac{1}{2}$ to $3\frac{1}{2}$ feet per 100, and is laid out with embankments following natural contours, as shown in Fig. 111, except that a total of 15 em-

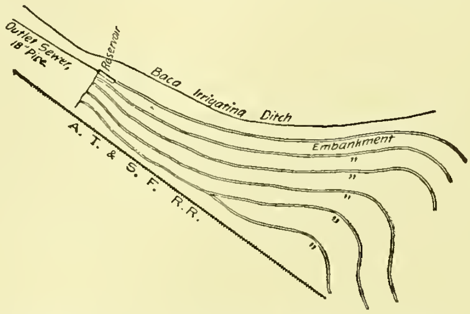


FIG. 111.—SKETCH PLAN OF SEWAGE FARM, TRINIDAD, COLORADO.

bankments have now been made. The embankments are from 25 to 50 feet apart and average about 1,500 feet in length. Wooden sluice boxes provide means for the passage of sewage through the embankments to lower areas. To the close of 1892 about $1,200 had been expended by Mr. John in preparing the farm to receive sewage.

It is stated that blue grass is proposed as a crop on the farm, for the reason that it will stand more frequent irrigation than any other crop.

FRESNO, CALIFORNIA.

A very interesting example of the use of sewage for irrigation is found at Fresno, California, where the city pays $5,000 per year for the disposal of its sewage, and the contractor distributes the sewage over land which he rents to Chinamen for market gardens.

The population of Fresno has increased from 1,112 in 1880 to 10,-818 in 1890. A public water supply was introduced in 1876 by the Fresno Water Co. The city put a sewerage system in operation in January, 1890. Shepard & Teilman, of Fresno, were engineers of the system, Mr. J. C. Shepard, of that firm, being city engineer at the time. Sept. 5, 1892, there were included in this system about eight miles of sewers on the separate plan, not including the outlet sewer,

which consists of about $4\frac{1}{2}$ miles of 24-inch vitrified pipe laid to a grade of $3\frac{1}{2}$ feet per mile. Jan. 1, 1893, there were in use about 600 house connections and six flush-tanks. In addition to the flush-tanks there is at four points a continuous flow of water into the sewers, about equal to a 2-inch stream under a 6-foot head. The lower end of the outlet connects directly with an irrigating ditch.

We are indebted to Shepard & Teilman for the information here given regarding the sewage farm, the remainder of which is presented substantially as furnished by them in September and October, 1892, as follows:

Prior to the construction of the sewers the city trustees considered the disposal of the sewage the great obstacle to be overcome; therefore they called for proposals to take care of the sewage for five years, the successful bidder to give a bond of $10,000 to protect the city from all damages which might arise therefrom after its delivery at the end of the pipe. Alexander McBean, of Oakland, was the lowest bidder, and his bid of $5,000 per annum was accordingly accepted. He purchased 80 acres of land at the end of the outlet sewer, and for one year the sewage ran upon it without any attention or care, except when occasionally some neighbor saw fit to take it for irrigation. The second year ditches were constructed and the land leased to Chinamen for vegetable gardens, and for the last two seasons it has been used for irrigating gardens and vineyards.

The land is all under cultivation with all the various kinds of vegetables commonly in the market, such as potatoes, yams, parsnips, lettuce, celery, beans, peas, and corn. It is customary to irrigate vegetables in furrows only. Trees and vines are preferably irrigated in furrows also. Grasses would be flooded, but Messrs. Shepard & Teilman have no knowledge of sewage used on grasses at this farm.

As to the amount of sewage used on the 80 acres, definite statements are lacking. The 24-inch outlet sewer, on a grade of $3\frac{1}{2}$ feet per mile, runs continuously, it is judged, about one-third full, but what proportion of the flow is used on the sewage farm is unknown.

Mr. H. Burley, the superintendent of the farm, states that he can see no difference between irrigating with sewage and clear water. It is possible that the land may produce good crops longer by the use of sewage, but that, he considers, is still to be proved. The general impression is that sewage is superior to clear water for irrigation. The sewage farm is an exceptionally poor piece of land, but nevertheless it produces fairly well with sewage irrigation. Neither Messrs. Shepard & Teilman nor Mr. Burley have any information as to what a similar piece would do if irrigated with clear water only.

When sewage is put upon the land without more dilution than is given by the flushing water, unless the land is cultivated within a day

or two, there is quite a stench, but when cultivated this disappears. Thus far there has been no complaint regarding the sewage farm, and as the matter stands the $5,000 is in effect a yearly pension to the contractor.

When not needed on the farm, the sewage is allowed to flow in the irrigating ditches for miles beyond; in this way it becomes very much diluted, and in the irrigating season is used throughout the country below the sewage farm proper.

Pasadena, California.

After an unfortunate experience with the Pacific Sewage Co.—an organization which agreed with the city to construct a disposal system similar to that in use at Atlantic City, New Jersey, but failed to do so—and after two years of litigation over right of way for the outlet sewer, the city of Pasadena in the middle or the latter part of 1892 began the preparation of a farm for the disposal of the sewage of the city. It is expected that this farm will be put in use in the season of 1893, as described below.

Pasadena is a city of comparatively recent origin, its population in 1880 having been but 391. The present population is estimated at 6,000, the census of 1890 showing 4,882 inhabitants. The construction of a sewerage system was begun in 1887, and in 1891 nearly five miles of sewers had been built within the city limits. August Mayer, C.E., of Pasadena, is the engineer of the whole system, which is of the separate type. We are indebted to Mr. Mayer for the following information relating to the sewage farm, the matter having been furnished in November, 1892:

The city of Pasadena lies in the midst of the San Gabriel valley, at the foot of the Sierra Madre mountains, 10 miles northerly from the city of Los Angeles and about 30 miles from the Pacific ocean. Its elevation above the latter may be taken at 900 feet, or about 600 feet above the main part of Los Angeles. The soil around the city, and especially that close to the mountains, is sandy, with excellent underdrainage. The general slope toward the ocean in the vicinity of the city is 2 feet per 100 feet. The grades obtainable for sewerage in the city, with one or two exceptions, are excellent. The average annual rainfall amounts to 20 inches, which is precipitated chiefly during the months of January, February, March, and April. The average temperature during the rainless eight summer months may be taken at 85° F. The air is dry.

Wherever water is obtainable for irrigation, citrus fruit is principally raised, while the unwatered land is fit only for the raising of some deciduous fruits, grapes, and barley; the latter being chiefly cut in this

vicinity before its maturity and used for hay. Bare land is worth $100 per acre without water, while watered land is held at about $600 per acre. Irrigation, therefore, makes the land valuable, and since water is here only obtainable from springs or storage reservoirs, of which latter there are none at this place at present, waste of water is hardly ever met with. It appears, therefore, that the circumstances for successful sewage disposal by means of irrigation, from a financial as well as sanitary standpoint, are favorable.

The sewage farm is owned by the city, and comprises 300 acres of land situated about four miles from the city in a southeasterly direction, in a well-settled part of the valley. The soil is a sandy loam, mixed with some alkali. It has the capacity of absorbing a considerable quantity of water. It is estimated that for the present only 40 acres will actually be required for the disposal of the sewage, although

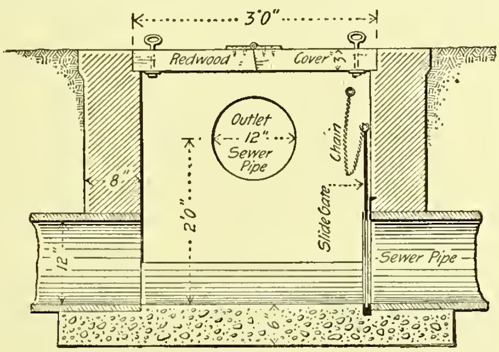


FIG. 112.—SKETCH OF SEWAGE OUTLET GATE, PASADENA, CALIFORNIA.

the sewage may be spread over a much larger area for the purpose of irrigating crops on the remainder of the farm. Most of the land will probably continue to be devoted, as at present, to the raising of barley-hay until fruit orchards are planted. The land originally cost $125 per acre, or a total of about $40,000, including some extra expenses. The gross yield in barley-hay, without irrigation, is $4,000 per annum, or 10 per cent. on the cost; the net yield amounts to about $3,000, 7½ per cent. on the money invested.

It is the intention to devote the land irrigated with sewage to the raising of vegetables, berries, and citrus fruits, and perhaps walnuts and alfalfa. The latter yields about seven crops per annum, or about 10 tons per acre, and is sold for $10 to $15 per ton. It stands any amount of irrigation at all seasons, and the sewage may be crowded on it at any time. Vegetables are calculated to yield $25 net per acre, while berries, as a rule, yield from $100 to $200 per acre per annum. Citrus fruits often net from $150 to $400 per acre per annum. With sewage irrigation, Mr. Mayer thinks these figures may possibly be exceeded.

As seen from the section of the outlet gate, Fig. 112, the sewage is taken from the sewer in much the same manner as water from irrigating pipes, by the simple closing of a cast-iron slide gate built into a man-hole, through which the pipe leads. The sewage is thus backed up into the sewer until it rises nearly to the top of the man-hole, whence it finds its way through a joint of sewer pipe into the main carrier, an earthen ditch 20 inches wide at the top, 10 at the bottom, and 10 inches deep. This carrier has a grade of from 4 to 6 inches in 100 feet. The land which the main carriers cover is divided into fields 100 feet in width and from 200 to 400 feet in length. The slope of the fields at right angles to the main carriers is $1\frac{1}{2}$ to $2\frac{1}{2}$ feet per 100 feet. To irrigate the fields a dam of earth or of redwood board is inserted in the carrier at the lower end of the field, and the sewage is thus diverted into numerous small furrows from 3 to 6 inches deep and one foot apart, previously made with a common cultivator. Each field is expected to take the sewage for at least 12 hours. After the first soaking the dam is removed, and the next field in order will receive its charge, and so on. As soon as the ground permits, say in about two days, field No. 1 will be thoroughly cultivated, to keep the ground from baking hard and to allow the air to act upon the soil. This is the common course adopted in this vicinity for irrigation with pure water.

Fruit trees are planted in regular lines about 20 feet apart each way, which permits the manner of irrigation described in the foregoing. The side and bottom walls of the main carriers will be raked over with a garden rake whenever it becomes necessary to prevent the ditch from becoming foul.

Berries are to be planted in rows about 8 feet apart, and the sewage will be led in between the rows so that the ground can be well cultivated. Vegetables may be planted in single or double rows, as the case may require, and the sewage will be conducted in between the rows or fields in flat trenches, which are to remain filled until the ground from trench to trench is thoroughly saturated with the sewage water, when the trenches will be drained, and after having dried off sufficiently they will be cultivated.

Redding, California.

Redding is one of the smallest towns in the United States using sewage for irrigation or having a sewerage system; its population in 1890 was 1,821, and in 1880 but 600. A separate sewerage system was built in 1889 by the town, with the city engineer, S. E. Brackins, as engineer, and Bassett & Touhey, Sacramento, as contractors, who also entered into an agreement to dispose of the sewage for 40 years.

January 1, 1893, there were 2.9 miles of sewers and seven 112-gallon flush-tanks in use.

The following description of the sewage farm and matters pertaining to the disposal of sewage has been prepared from material furnished in October, 1892, by L. F. Bassett, C.E., the present owner of the farm:

Redding is situated on slightly rolling ground, at an elevation of 550 feet above the sea. It is bordered on the northeast and southeast by the Sacramento river. The climate ranges from 16° above zero in the winter to 107° F. above in summer. Most of the season the atmosphere is dry and evaporation rapid.

It was the original intention of the town to discharge its sewage into the Sacramento river, but objection was made at Sacramento, where water is taken from the river to supply the city, and the State Board of Health gave notice to the authorities of Redding not to discharge the sewage into the river. The town authorities thereupon requested bids for taking care of the sewage, and a contract was entered into for a term of 40 years, the sewage to be disposed of at $300 for the first year, the amount of yearly payment thereafter to increase in proportion to the increase of the assessment roll.

The contractors immediately purchased a tract of about 100 acres of land within the corporate limit, shown by Fig. 113, and prepared a portion of it, about a mile from the built-up part of the town, for the utilization of the sewage by irrigation. The land selected is comparatively level, and the soil a sandy and gravelly loam 4 to 6 feet in depth, underlaid with gravel. Land better adapted to the purpose would be hard to find. About 10 acres have been prepared for irrigation by levelling and constructing open carrier ditches, elevated above the surface of the land to be irrigated.

The sewage is applied directly to the land by the broad surface irrigation system, either by being run in furrows between rows or spread over the surface, according to the requirements of the crop. The sewage has been applied to various crops, grain, asparagus, potatoes, turnips, beets, orchard and some garden truck. It has been principally used in raising fruit trees for nursery stock, the young trees being irrigated between the rows. About five acres are used as a nursery.

Generally the land is cultivated as soon after an application of sewage as the soil becomes dry enough. Part of the year it is necessary to put the sewage on land on which no crops are growing. It is then customary to run the sewage on the same piece of land for several days in succession, and after the land becomes sufficiently dry, to plough or cultivate it. This is more particularly the case in winter, when there is sufficient moisture for crops without irrigation.

The sewage is not allowed to flow continuously on to the land, as too much time would be required in taking care of it; besides which the ordinary flow is not of sufficient volume to operate successfully. As shown by the plan, Fig. 113, a reservoir was constructed at the outlet of the sewer, at the upper line of the sewage farm. This reservoir has a capacity of 75,000 gallons, which is about equal to the daily flow in the dry season. Each morning the outlet is opened, and the contents discharged in from two to four hours, as desired. The bottom and sides of the reservoir are so constructed that everything gravitates to the outlet, and special cleaning is seldom necessary. An abundant supply of water from the town water-works is at hand for use if required. The reservoir is covered with a rough board structure, and a vent chimney of lumber is carried to an elevation of about 60 feet. This has been sufficient to prevent any nuisance, and none is complained of, although the reservoir is alongside the public road.

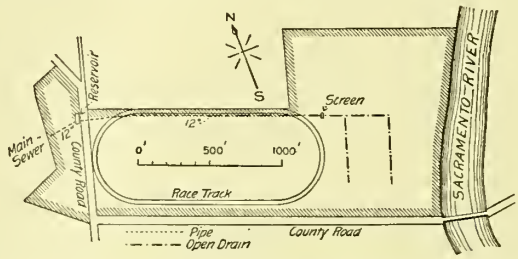


FIG. 113.—PLAN OF SEWAGE FARM, REDDING, CALIFORNIA.

It is stated by Mr. Bassett that no difficulty has been experienced in preventing a nuisance on the irrigated lands. Care and attention to secure proper distribution and cultivation are required, and with these the results have been fairly satisfactory. There is sometimes a slight odor in the immediate vicinity of freshly irrigated land, or where the sewage becomes ponded previous to its subsidence into the soil, but even this odor is not noticeable at a distance of 200 feet.

A screen near the upper line of the irrigated lands (see Fig. 113) catches such large objects as might cause an obstruction in the ditches or interfere with the free flow of the sewage over the soil. There has been no underdrainage, as none is required, the soil being very porous and underlaid with an extensive bed of gravel.

There has been some prejudice against the sewage farm, but this is gradually dying out. The most of this is stated to have been manifested by two landowners immediately south of the tract under irrigation, who from the first objected strongly to the location of the sewage farm in their vicinity. In June, 1892, one of the objectors had the proprietor of the farm arrested for maintaining a public nuisance. At

an examination, held shortly afterward, the examining magistrate decided that the evidence was not such as would secure a conviction, and the case was dismissed.

Besides the sewage, fresh water from the Sacramento river, sufficient for 40 acres, is available for irrigation at this farm.

Los Angeles, California.

The city of Los Angeles, California, is now the second in size in the State, having increased from a population of 11,183 in 1880 to 50,395 in 1890. Water-works were built in 1862, but the date at which sewers were first put in operation is not at hand, though it was not until 1887 that a comprehensive plan for sewerage was prepared. In that year sewerage plans were prepared by Fred Eaton, M. Am. Soc. C.E., who was then city engineer of Los Angeles. The sewers were designed on the separate system, and proportioned for a final population of 200,000, allowing 100 gallons of sewage per head per day, with a maximum flow of 150 gallons. These plans were reviewed and approved by Rudolph Hering, M. Am. Soc. C.E. They, however, failed to receive the sanction of the final municipal authority.

In 1889 Mr. Eaton presented another plan for the drainage of the city, somewhat more elaborate than the former. The rapid growth since 1887 and the great improvements in street paving, as well as the prospects of future development had so far changed the conditions as to lead to the conclusion that more liberal provision for sewerage should be made than the previous plan contemplated. The subject was therefore treated on a larger scale than in the previous plans. The street sewers were to a great extent planned on the combined system, while an outfall to the sea was provided *via* Ballona, instead of *via* Centinella Rancho, as in the previous plans.*

In order to keep the cost of the outfall, which would of necessity be several miles in length, within bounds, provision was made for discharging storm-water directly into the Los Angeles river and other natural water-courses by storm overflows. In this way the main outfall was kept down to a size about sufficient to convey the dry-weather flow of the sewage of the city.

In spite of the various restrictions, the cost of the enlarged plan was considerably greater than that of 1887. When put before the citizens to vote bonds for its execution, the project was defeated and therefore abandoned.

At this time the daily dry-weather flow of sewage amounted to about 7,000,000 gallons per day, and was disposed of by irrigation on a sandy tract of 1,700 acres adjoining the southern limits of the city and known

* Los Angeles is on the Los Angeles river, about 12 miles from the Pacific ocean.

as the Vernon district. The sewage was taken at the city limits by the South Side Irrigation Company, who distributed it to the different land-owners of the district through open ditches owned and controlled by the company. The lands reached by the sewage ditches had, previous to irrigation, yielded a yearly rental of about $2.50 per acre; but with sewage irrigation they easily rented for from $15 to $25 per acre per annum. Throughout the whole district the sewage was the only water that could be depended upon for irrigation, except on a few acres reached by the surplus waters of the irrigation ditches in the city of Los Angeles.

During the era of real estate speculation (1885-89), a great deal of the land of the Vernon district was cut up into lots and sold. Residences and improvements were constructed throughout the district, and for the following reasons the sewage began to be considered the source of a public nuisance: (1) It was carried in open ditches; (2) the people were obliged to take it, whether they wanted it or not; (3) the irrigable area was considerably reduced by subdivision into house lots, while by reason of the rapid growth of the city the quantity of sewage was continually increasing; and (4) the owners of the lands were more interested in selling for residences than in developing for cultivation.

Finally injunction suits were brought against the South Side Irrigation Company to compel it to convey the sewage in closed conduits through the lands of such owners as objected to open ditches, and also to restrain the company from delivering sewage to lands when not required thereon for the irrigation of crops. As further complicating the matter, the city had only one outfall and was unable to control the volume of sewage; again, whatever volume was discharged at the city line the Irrigation Company was obliged to dispose of. The result of the controversy was that the injunctions were granted, whereupon the Irrigation Company turned the sewage into the Los Angeles river, where it has since gone to waste, except that a small area has remained under irrigation.

In the meantime the question of ultimate disposal was pressing for solution, and finally, in November, 1889, the council ordered that "all plans and propositions for sewering the city, and all proposals for the disposal of the sewage, be referred to a Commission of Engineers," to consist of Rudolph Hering, M. Am. Soc. C.E., Fred Eaton, M. Am. Soc. C.E., George Hansen, C.E., George C. Knox, C.E., and August Mayer, C.E., who reported under date of December 23, 1889.

The Commission took up the various projects which had been submitted from time to time, including those of a citizens' committee which had reported, a short time before the appointment of the Commission, a project for sewerage embodying substantially Mr. Eaton's plan of 1887; but instead of an outfall to the sea they advocated the

erection of several detached stations at which all the sewage would be treated by precipitation or filtration, and the effluent used for irrigation to the south of the city. The estimates submitted by the citizens' committee were considerably lower than either the engineer's estimate of 1887 or that of 1889. The precipitation plan was, however, shown when analyzed to entail much larger capitalized expense than the citizens' committee had estimated.

In its report the Commission of Engineers took the matter up in detail, and presented estimates on the various routes and plans which had been under discussion, together with concise statements of the problem of sewage disposal at Los Angeles, and concluded "that on account of the nearness of large areas of irrigable lands and the comparative distance to the ocean, a disposal of the sewage by irrigation is the most suitable method for Los Angeles."

The problem of disposal by irrigation was, however, somewhat complicated by the fact that the city owned no lands upon which to irrigate, and that consequently disposal by irrigation must be subject to arrangements with the land-owners; and in order to obtain their views a circular was prepared and placed in the hand of every land-owner that could be reached in the Vernon and Florence districts and in the direction of Ballona, these being the localities to the south and southwest of the city in which disposal by irrigation would be naturally applied. The following are the questions asked in this circular:

1. Do you desire sewage for irrigation?
2. Would you use crude sewage?
3. Would you prefer crude sewage?
4. Would you use purified sewage?
5. How many acres of land do you own?
6. How many acres would you irrigate?
7. What is the nature of your soil? (Sandy, loamy, alkali, or moist.)
8. Do you wish the sewage for the dry season only?
9. Would you take the sewage for the wet season only?
10. Would you enter into contract with the city of Los Angeles, and give bonds to take care of its sewage at all seasons, and if so, how long?
11. Would you make use of the city's sewage at times when you needed it, if its system was provided with an outfall sewer to the sea?
12. Do you use well water for household purposes?
13. What is the depth of your well?
14. Is your well tubed?
15. In boring and digging did you meet with any impervious layer of clay or hardpan?
16. Would you object to the irrigation with sewage on lands in your vicinity?

A great number of answers were received, which are presented in four tables in the report. The following from the report gives the main points of these four tables:

Table No. 1 shows for Vernon and Florence that thirty-five property holders, owning 3,033 acres of land, desire sewage either crude or pure for irrigation;

twelve persons, controlling 367 acres, will make use of purified sewage only; thirty-two persons, owning 2,955 acres, will take sewage for the dry season only; sixteen persons, owning 571 acres, would take the sewage during the wet season; three persons, controlling 48 acres, intend to use sewage only if the city provides its sewer system with an outfall to the sea; 43 persons, owning all the property canvassed, except 70 acres, refuse to guarantee by contract and bond to take the sewage of the city at all seasons; three persons, owning 70 acres, signify their willingness to enter into contract with the city and give bond to take the sewage for all seasons; forty-five persons state that they use well water for domestic purposes. Table No. 2 shows for Vernon and Florence that one hundred and thirty-three property owners, controlling 5,125 acres, positively refuse to use sewage for irrigation, while one hundred and twenty four of them object also to sewage irrigation in their vicinity. Table No. 3 shows that five persons, owning 1,026 acres of land in the direction of Ballona, will take the sewage for irrigation, crude or purified; six persons, owning 1,028½ acres, will take the sewage for the dry season; no one in that vicinity offers to take sewage during the wet season; all six persons refused to enter into contract with the city to take the sewage at all times, while five use well water for domestic purposes. Table No. 4 shows that twenty-two property holders in the direction of La Ballona, controlling 1,711 acres, refuse to irrigate with sewage, while twenty-one of them also object to sewage irrigation in their vicinity. Most of the land is reported to be sandy or sandy loam.

As stated by the Commission, the conclusions which are reached from the foregoing point to the following:

(1) That a great portion of the lands lying south of the city are suitable for irrigation purposes. This the Commission can affirm from personal inspection.
(2) That an insufficient amount of land is offered for a permanent disposal of the city's sewage.
(3) That enough land is, however, available for a disposal during the dry season.
(4) That an insufficient amount of sewage would be accepted in winter.

The Commission continued the discussion as follows:

The problem, therefore, requiring a solution, is the finding of a practicable method of disposing of the sewage during the winter months.

In order to have some tangible data regarding the length of time during which sewage is not desired by irrigators, we have asked and received a statement thereof from Mr. Henry Martz, President of the South Side Irrigation Company, showing that since the summer of 1888 the sewage had to be run to waste during the following periods: From Nov. 13, 1888, to Feb. 14, 1889, 93 days, no sewage was used. From Feb. 14 to March 12, 1889, 20 days, one-half of the sewage was used (about 3½ cubic feet per second on 650 acres, or 3,480 gallons per day per acre.) From March 12 to April 20, 1889, 39 days, no sewage was used. From April 20 to Sept. 30, 1889, 163 days, all the sewage was used (about 8 cubic feet per second on 1,700 acres, or 3,040 gallons per day per acre). From Sept. 30 to Oct. 20, 1889, 20 days, one-third of the sewage was used (about three cubic feet per second on 1,700 acres, or 1,140 gallons per day per acre). Oct. 20 to Dec. 15, 1889, 56 days, no sewage was used. Therefore, between Oct. 20, 1888, and Oct. 20, 1889, on 187 days, all sewage was used; for 26 days, one-half of it; for 20 days, only one-third of it; and for 132 days none was used. Between Sept. 30, 1888, and Sept. 30, 1889, on 207 days, all the sewage was used; for 26 days, one-half of it, and for 132 days no sewage was used.

During a wet year, the number of days when the water-takers do not want the sewage is still greater; but for the purpose of a comparative estimate of cost, we have assumed an average time of 130 days per annum, during which the sewage must be disposed of by other methods than the present one. Land cannot be properly cultivated which must receive sewage at all seasons. The crops at certain stages of growth will be positively injured by irrigation. The greatest benefit is derived by land-owners, if they are placed in such a position that they can take the

sewage whenever and in whatever quantity they desire. Under such circumstances land can be rented at higher rates than otherwise, and consequently sewage water can be sold at much better prices to the irrigators.

After further discussion of the several questions presented, the Commission arrived at the following

Conclusions.

(1) There is no legal authority to pollute a watercourse and to create and maintain a nuisance therein, and therefore crude sewage cannot be discharged into the Los Angeles river or any other available stream.

(2) For this reason it is not within the province of the Commission to consider an outfall sewer to the river not far from the city, or to any other watercourse within reach, without making provision for the proper purification of the sewage at the point of discharge.

(3) If the annual cost of purifying the sewage by precipitation is capitalized and added to the cost of a short outfall sewer, the total expense of any such method of disposal in this locality is far too expensive, and the Commission cannot recommend it.

(4) The filtration of sewage of the winter months upon 800 acres of land either near the Los Angeles river or the Ballona creek, is more expensive than the cost of an outfall to the sea, but this difference is not so great that it might not be balanced by other considerations than the question of cost.

(5) The expense of taking care of the sewage during the winter months may possibly be balanced by the receipts from the crops raised during the summer months, but this conclusion depends greatly upon the skill, intelligence, and integrity of the management.

(6) The operation of filtration areas on the part of the city would oblige it to enter directly or indirectly into competitive business for the raising and sale of crops, which is to be looked upon with disfavor.

(7) The owners in severalty of those large areas, which by reason of their size can alone profitably receive the amount of sewage upon which the present estimate is based, refuse to enter into any engagement to take this sewage unless the city guarantees them against any loss resulting from litigation.

(8) The city can give this guarantee or can guarantee the general public against the creation of a nuisance only when it is in position to dispose of the sewage properly at all times.

(9) Other things being equal, an outfall to the sea which requires a minimum of care and attention on the part of the municipality, is therefore to be preferred.

The outfall sewer to Long beach along the Los Angeles river is the most expensive among the sewers projected to the ocean.

(10) There are prospective objections to the disposal of sewage at Long beach by an outfall sewer along the river, on account of the shoals and sloughs prevailing in that locality, and eventually the sewage might have to be removed further into the ocean by pumping.

(11) The only two remaining lines of outfall sewers, namely, to points between Santa Monica and Redondo beach, are equally commendable from an engineering point of view, and the preference between them may be decided on the grounds of cost.

(12) The outfall sewer by Ballona route is the cheaper one, and therefore more preferable.

(13) The draining of the Cienega, and incidentally improving its value, may be accomplished by laying tiles in the same trench with the sewer, which tiles can drain into the creek.

(14) If the sewage is freed of its floating matter by screens placed on the line of the sewer near the coast, none of it can drift to points along the shore and there deposit.

(15) By carrying the outfall 2,000 feet into the ocean from the shore and letting the sewage escape twenty-five feet below low water, no sewage will be traceable in the ocean water, even with strong currents, at a distance of one and one-half miles from the outlet, and a chemical analysis will be unable to detect any traces of sewage at a distance of two miles.

(16) While Los Angeles at the present time derives no income from the sale of its sewage for irrigation, and can presumably derive no income from such source whilst it is obliged to solicit landowners to receive the sewage and to guarantee the users against loss by litigation, it is unquestionably a fact that, with an outfall sewer, the city will be placed in an independent position, and will be enabled to sell the sewage at market rates to those who desire its use.

(17) The income from the sale of sewage, current rates, when the population of the city reaches 200,000, will be over three per cent. on the investment in building the outfall sewer.

(18) In view of the above, the Commission recommends the construction of an outfall sewer to Ballona, with possibly a temporary reduction in the cost by using a wooden flume in crossing the marshes near the sea, and by contracting for the sale of sewage water during the irrigation season.

According to statements made in October, 1892, by Mr. J. H. Dockweiler, the present City Engineer of Los Angeles, the city finally voted $395,000 worth of bonds to construct the outfall sewer from the southwest corner of the city to the Pacific ocean, a distance of 12 miles. This sewer, which it is expected will be completed during 1893, has been so located as to deliver sewage upon the lands at the highest possible level. Provision has been made to supply sewage from this outfall by gates and hydrants located at the commanding points, but the landowners will be required to make their own arrangements for conduits to their lands and for distribution. It is proposed to charge about $3 per acre per annum for the use of the sewage. It is stated that at least 20,000 acres of sandy soil are available for irrigation from the outfall sewer.

In the report of the State Board of Health of California for the two years ending June 30, 1890, there appeared a paper by Mr. D. G. McGowan, Health Officer of Los Angeles, from which the following extract is taken:

At the southeast angle of the city limits this water (sewage) is taken by the South Side Irrigation Company and conducted through a 22-inch cement pipe a distance of six miles to the sandy plains below the town of Florence. Though eagerly taken at first by the Chinese market gardeners for irrigating and enriching their truck patches, its prolonged use has been found to be a detriment, lessening the productive qualities of the land when it becomes well saturated with the sewage matters. It is a fact that lands upon which it has been used constantly for several years have been abandoned by their cultivators, or it has been necessary to pipe pure water upon them to take the place of sewage for the purpose of irrigation.

The above statements, when taken in connection with the prior explanation of the abandonment of the use of sewage from the ditches of the South Side Irrigation Company, lose much of the force which they seem to have by themselves. It is doubtless true that the land

was overdosed with sewage, and it is quite probable that little or no proper attempt at a rotation of crops was made.*

Santa Rosa, California.

The population of Santa Rosa in 1880 was 3,016, and 5,220 in 1890. The Santa Rosa Water Co. built water-works in 1873. A few streets were sewered on the separate plan some years ago, sewage being discharged into Santa Rosa creek, near the city limits. Complaints of pollution of the creek, followed by a lawsuit, led to the purchase by the city of between 18 and 19 acres of land about two miles from the city, to which an outlet sewer was built.

The farm is leased to parties who take care of the sewage for rental, using it for gardening purposes. The city can terminate the lease at any time. The year the farm was put in operation is not stated, but it was used as early as 1890, and probably at least one or two years earlier.

A slight rise near the end of the outlet sewer causes the coarser solid matter to collect. Once a day, or as often as is necessary, a gate is opened and the collected matter flushed out into a pit near the bank of the creek.

When not used for irrigation the sewage flows on to low land near the bank of the creek, which land is flushed at high water.†

Helena, Montana.

About one-fourth of the sewage of Helena is used for broad irrigation on a farm owned by the city and leased to Mr. A. T. Newbury for five years from 1890, prior to which it had been leased for about two years to another party whose name has not been given.

Helena had a population of 3,624 in 1880 and 13,834 in 1890. A sewerage system was put in operation in 1889. Jan. 1, 1893, there were 26.5 miles of sewers, receiving no rain-water except from roofs. There were on the same date 810 house connections, 310 man-holes with perforated covers, and 76 Field flush-tanks discharging every 12 hours 225 gallons. G. N. Miller, C.E., was engineer of the sewerage system.

The end of the outfall sewer connects directly with the distributing ditches of the farm. The sewage, when not used for irrigation, runs across the farm into and through two ditches extending for about 2½ miles to Ten Mile creek, a stream about 20 feet wide and 1 foot deep.

* In addition to the articles in Eng. News, vol. xxix., pp. 183–6 (Feb. 23, 1893), the further source of information in regard to Los Angeles sewage disposal is a Report of the Board of Engineers upon the Disposal of the Sewage of Los Angeles City, and its Sewer System, presented to the Mayor and Council of the City of Los Angeles, Dec. 23, 1889.

† Information furnished by Newton V. Smyth, city engineer, and J. L. Jordan, city clerk.

The city paid $6,100 in 7 per cent. bonds for the 40 acres of land included in the farm, which has received sewage for about four years. The farm has been leased, the lessee paying the city a rental of $200 in cash; he is further to plant 100 trees and make one acre of lawn per year, caring for the trees and lawn. It is said that the lessee raises vegetables and all kinds of nursery stock on the farm. In connection with the statement made below, that the farm has never paid the interest on the cost, it must be remembered that this could hardly be expected from the use to which the farm seems to be devoted; nor, for the same reason, can efficient purification throughout the year be expected.

The sewage is distributed over the farm by means of open ditches and is brought to the plants by flooding. It is utilized only in the growing season. The land is not underdrained.

The above information was given by Mr. Geo. K. Reeder, formerly city engineer, and by the present city engineer, Mr. Jas. S. Keerl. The following additional facts and opinions regarding the operation and success of the farm are given substantially as furnished by Mr. Reeder in July and September, 1892:

The sewage is only utilized in the growing season. During the winter months, or rather when the ground is so frozen that there is no absorption, the sewage is allowed to flow in the natural channels upon the surface. During some portions of the year, even when not used for irrigation, the sewage scarcely gets across the field before being absorbed or evaporated.

Mr. Reeder states that the farm has never proved a source of income to the city—in fact, it has never paid the interest on its cost—and has not proved a success in disposing of sewage throughout the whole year. His opinion is that the soil is not suitable for the purpose, it being a gravelly, sandy loam for a depth of six inches, beneath which is a bed of quite impervious clay and gravel. The land may become more suitable after years of working. The city authorities, in the lease, have virtually turned over all control of the sewage to the lessee, and thus far the tenants have done as they pleased.

As nearly as can be learned from the aldermen, the intention in establishing the farm was ultimately to convert it, or at least a portion of it, into a park, sewage to be supplied to the trees by means of porous tile. It has also been proposed to make it an absorption farm, the sewage to be turned on to one portion until it would absorb no more, then to another, and so on, each portion after drying out to be turned over by cultivation, to fit it for a new dose of sewage. This was to be done irrespective of seasons, and crops were to be a secondary consideration.

Cheyenne, Wyoming.

Regarding the former use of the sewage of Cheyenne for irrigation, the following information has been furnished by Mr. Fred Bond, city engineer, under date of Aug. 28, 1892 :

The sewage, direct from the sewer outlet, was discharged directly into the irrigating ditch of a private ditch owner, and mixed therein with water already in the ditch, which was taken from the creek a little further up, or above the point where the connection with the sewer was made. In this way the creek water and sewage were mixed and carried to the land to be irrigated. The party using the sewage did not pay for it, the obligations between the city and himself being considered mutual. It is stated that the sewage was so used for seven or eight years. The sewage is now discharged into the creek, about 2,500 feet below the point where it formerly entered the private ditch.

Cheyenne had a population of 3,456 in 1880 and of 11,690 in 1890. Sewers were put in use in 1883 on the separate plan. On Feb. 20, 1891, about five miles of 9- to 15-inch vitrified salt-glazed sewer pipe had been laid.

The use of sewage for irrigation was stopped on account of the extension of the outlet sewer to discharge at a point below the ditch of the party who made use of the sewage.

Stockton, California.

Provision for the use of sewage for irrigation has been made at Stockton, California, but the fact came to our attention too late to secure exact information. The construction of a sewerage system was begun in 1891, under the direction of Mr. George Atherton, city surveyor. The sewage is pumped into an outfall sewer 14 inches in diameter and two miles long, discharging into the Stockton river. It is stated that at regular intervals on the outlet sewer, gates are placed " by means of which the property owners turn the sewage upon the land during the dry season for irrigation purposes."

The population of Stockton in 1890 was 14,424.

In reviewing the foregoing information in regard to sewage disposal in the extreme Western States, two conclusions seem fairly indicated, namely, that (1) there is evidently a large field for sewage irrigation in that region ; and (2) that thus far a portion of the sewage irrigation attempted has been of a somewhat unsatisfactory character, by reason of either lack of attention to the details or else a lack of thorough information about this special form of irrigation. Both of these difficulties will undoubtedley correct themselves as the country develops and new plants are put in operation.

CHAPTER XLV.

MISCELLANEOUS PLANTS.

In order to include within the limits of one volume descriptions of all the sewage purification plants known to be in operation in the United States in the early part of 1893, it is necessary to touch lightly upon the few remaining works, especially as some of them were put in operation since the manuscript for this book was sent to the printer.

Sub-surface Disposal at Lenox, Massachusetts.—Old and New Plants.

A sewerage system was built at Lenox, Massachusetts, in 1875–6, with Col. Geo. E. Waring, Jr., M. Inst. C.E., as engineer. The population of Lenox was small at that time, having been only 2,043 four years later, or in 1880, and money for an outfall sewer to the river was not available. A combined system of sub-surface and surface irrigation was therefore adopted. The outlet sewer emptied into a combined screening and flush tank, with a capacity of about 500 cubic feet, from which a Rogers-Field siphon discharged the sewage into a chamber with two outlets. One of these outlets connected with some 10,000 feet of sub-surface irrigation pipes, and the other to a surface carrier from which the sewage flowed over the top of the ground.

The sub-surface pipes gave much trouble on account of becoming clogged with grease and other solid matter, necessitating the frequent and often continued use of the surface carriers. For the past few years settlement has been effected in the screening tank, and the sewage has all been discharged upon the surface.

The total area employed for both sub-surface and surface disposal was only about $1\frac{1}{2}$ acres, which soon became overtaxed.*

Lenox, as is well known, is built on the Berkshire hills. The growth of the town has latterly, it appears, been away from the old disposal area on another slope. In 1887–8 an outfall sewer was built to receive the sewage of the newer portion of the town, and a new disposal area was put in operation early in October, 1888, Mr. E. W. Bowditch, of Boston, having been engineer. It was proposed early in 1893 to pump to the new outfall sewer the sewage from the district tributary to the old area.

* For further details see Col. Waring's Sewerage and Land Drainage.

The new disposal area consists of 17 acres of land some two miles from the village, on a quite steep hillside near the Housatonic river, into which the effluent is discharged.

A 12-inch outfall sewer ends in a circular well provided with a swinging gate to turn the sewage at will into either side of a settling tank. Sewage is drawn from the top of the settling tank to a pipe-line connecting with six wells or man-holes, in the bottom of which are thimble-shaped iron stopper gates provided with lift-rods extending to the top of the man-hole. When these gates are shut down the sewage flows beneath the man-holes, and when they are raised it flows into them, the inflow varying with the height to which the thimble-shaped stopper is raised.

From the man-holes the sewage passes into stone drains covered over with earth, by means of Akron pipe laid near the top of the drains, with bell-joints on their lower ends, through which the sewage escapes. There were, in June, 1892, six of these drains, each some 300 to 400 feet long.

Sludge is drawn from the settling tank to a pit and covered with earth. Mr. T. Post took charge of the sewerage system in 1888, and has remained in charge since that time.*

Disposal upon Land and Sedimentation at Amherst, Massachusetts.

In 1881 the college town of Amherst, which in 1890 had a population of 4,512, first conducted a small amount of sewage to a settling tank, from which the sewage was drawn through ditches on to land, and the sludge also removed and applied to land.

In 1891 the outlet sewer was extended and a settling tank in two compartments built. Mr. Henry Hastings agreed to take care of the settling tank for five years from 1891 for the use of the sludge. The clarified sewage flows to Fort river, about 520 feet distant.

About one-fourth of the sewage of the town goes in another direction, and is used for broad irrigation on a tract of grass land, which has been much improved by the sewage.†

Disposal on Land at Greenfield, Massachusetts.

Since about 1882 the sewage of Greenfield has been discharged on to a piece of meadow land. The outfall sewer ends abruptly on the edge of the meadow. Some pains were apparently taken to distribute the sewage over the land, but in June, 1892, the sewage

* For further details of the old and new Lenox plants see Eng. News, vol. xxviii., pp. 33 and 53-4 (July 14 and 21, 1892), respectively.

† For further details see Eng. News, vol. xxviii., p. 54 (July 21, 1892).

was entirely without control, some of it going on to the meadow and some into a small brook leading to the river. So far as can be learned, the owner of the land wished and secured the discharge of sewage upon the meadow for fertilizing purposes, but upon his death the outlet was neglected and has remained in that condition since.*

Mechanical Separation or Filtration at Leadville, Colorado.

The sewage of Leadville is passed through a body of sand and gravel about 6 or 7 feet deep with an area of some 24 square feet, the effluent being discharged into California gulch. The disposal bed is in two sections, for alternate use. The sewerage system was built in 1886 by the Leadville Sewerage Co., of which C. N. Priddy is superintendent. In March, 1891, there were 40 sewer connections. In the spring of 1892 the yearly cost of caring for the disposal bed was given as $450. The population of Leadville in 1890 was 10,834.†

Mechanical Separation at Atlantic City, New Jersey.

The system of purification in use at Atlantic City consists of an elevated bed, in which sand with hay below is used as a separating material, and from which the effluent falls in small streams or in drops some three feet to gathering gutters which lead to an effluent pipe. It is claimed for this system that filtration is supplemented by aëration, and thus that greater purification is secured. The rate of treatment at Atlantic City is so rapid that only partial mechanical filtration, or straining, can be expected, and this is all that is claimed for the plant by its superintendent.

Atlantic City is a well-known seaside resort which has many visitors in the winter, but a much larger number in the summer. Its population in June, 1890, was 13,055, against 5,477 in 1880. It is said that during the height of the summer season as many as 150,000 people are to be found in the city on some Sundays.

The sewerage and sewage disposal systems were built in 1885 by a private company, and are now owned and operated by the Atlantic City Sewerage Co.

All the sewage at Atlantic City is pumped, the pump-well being located in the pumping station and being ventilated to the chimney. Features of both the pumping plant and filter beds are covered by patents, and the method of disposal is called the "West system" by the owners of the patents, the National Sewerage and Sewage Utilization Co. of New York City. It is only fair to add that a comparatively

* See Eng. News, vol. xxviii., p. 196 (Sept. 1, 1892), for additional facts regarding sewage disposal at Greenfield.

† Eng. News, vol. xxix., p. 52 (Jan. 19, 1893).

slow rate of filtration was the design of the patentee of the system.

The daily sewage pumping records for the year ending November 30, 1892, illustrated by diagrams and analyzed in detail, are given in Chapter VII., "Quantity of Sewage and Variation Rate of Flow." *

Electrical Treatment at Brewsters, New York.

Brewsters is a small village in the Croton watershed, about 52 miles from New York City. To prevent pollution of the New York water supply the Department of Public Works has built some sewers in the village and caused a plant to be erected for the treatment of the sewage. Salt and water, at the rate of 160 lbs. of the former to 1,000 gallons of the latter, is subjected to an electrical current of about 700 ampères and 5 volts, the current passing through a positive electrode of copper, plated with platinum, and a negative electrode of carbon, both immersed in the brine. The electrically treated solution is discharged directly into the outlet sewer, through which it flows for a few hundred feet to a series of trenches in meadow land, perhaps 500 feet from the east branch of the Croton river. The treated sewage soaks off into the ground as best it can. The salt used costs about $4 per ton. The power to drive the dynamo is furnished by a 20-H. P. horizontal boiler and a 15-H. P. engine. The dynamo is 4-H. P.

The volume of sewage is very small, being that derived from some 35 buildings, and no definite figures regarding the operation of the plant are available. The plant was built by the Woolf Electric Disinfecting Co., of New York City, and was devised by Albert E. Woolf, also of New York. The contract price was $5,000, which the contractors claim is below the actual cost of the plant.† It is reported that the treated liquid is discharged into the sewer at the rate of 1 part to 100, which with a solution of the strength stated above is equivalent to 1,600 lbs. of salt to 1,000,000 gallons of sewage.

Chemical Precipitation at Canton, Ohio.

The accompanying plan and sections, Figs. 114 and 115, show the general features of the works at Canton, which were put in operation about May 1, 1893. Chemical precipitation works were recommended by Samuel M. Gray, M. Am. Soc. C.E., in March, 1887, who also prepared plans for the works. The plant was finally constructed after the detailed plans of Mr. L. E. Chapin, Assoc. M. Am. Soc. C.E. The tanks are operated on the continuous plan. The chemical mixers and

* The above is extracted from Eng. News, vol. xxix., pp. 122–4 (Feb. 9, 1893).
† See Eng. News, vol. xxx., p. 41 (July 13, 1893).

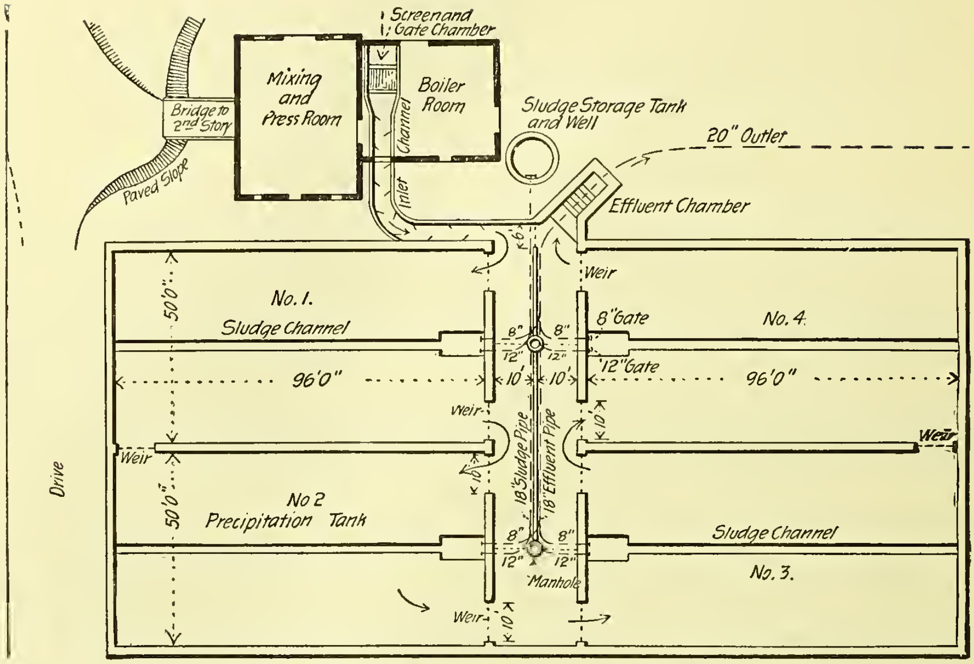


FIG. 114.—PLAN OF CHEMICAL PRECIPITATION PLANT, CANTON, OHIO.

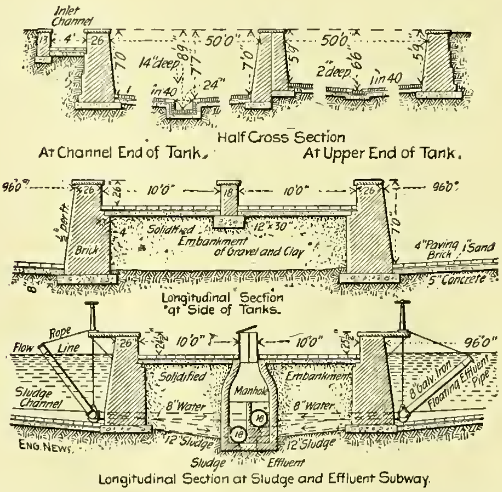


FIG. 115.—SECTIONS OF CANTON PRECIPITATING TANKS.

sludge compressing machinery were furnished by the Bonnot Co., of Canton. The population of Canton in 1890 was 26,189. In the spring of 1893 about 16 miles of sewers and some 900 house connections were in use.*

Chemical Precipitation at Chautauqua, New York.

In the summer of 1893, works were put in operation for the treatment of the sewage of Chautauqua, the well-known summer resort on the lake of the same name. There are four settling tanks. The chemical mixers and filter presses were made by the Bonnot Co., of Canton, O. Early in August the sewage of 5,000 people, some 130,000 gallons per day, was being treated, with a resultant pressed sludge of 2,500 pounds, of which 40 per cent. was water.

Samuel M. Gray, M. Am. Soc. C.E., Providence, R. I., was engaged as consulting engineer for the plant, and under his direction competitive plans, with proposals for construction, were received. The contract was awarded to Wm. B. Landreth, M. Am. Soc. C.E., Jamestown, N. Y., who built the works after the designs submitted by him, Thos. McKenzie, Jun., Am. Soc. C.E., acting as constructing engineer.

Chemical Precipitation at the World's Columbian Exposition, Chicago.

The sewage of the World's Columbian Exposition of 1893 was treated by the German vertical tank system, the plant being modelled directly after that at Dortmund, designed by Karl Kinebühler. Fig. 116 shows a combined section and elevation of the tanks. The sewage is forced to the elevated central receiving and distributing tank by means of Shone ejectors stationed about the Fair grounds. From the distributing tank it passes to either or all of the four precipitating tanks, receiving sulphate of alumina, or copperas, and lime on its way. The alumina or copperas is mixed with the sewage by means of a revolving screw placed in a special casting, as shown by the illustration, and the lime by the core mixer, also shown in the illustration, Fig. 116. Different chemicals and different amounts of any chemical can be used at the same time, and the results noted by means of the frequent chemical and bacteriological examinations which are being made.

The sludge may be drawn off while the tanks are in operation, through the sludge-pipe at the bottom of the tanks to one of three sludge-tanks, each 4 feet in diameter and 8 feet high, giving a capacity of about 100 cubic feet. The sludge is forced by means of compressed

* For additional information see Eng. News, vol. xxix., pp. 520–1 (June 1, 1893), and vol. xxx., pp. 60 and 61 (July 20, 1893).

air into one of two filter presses, made by Perrin & Co., Chicago. Each press has 50 cells, 36 inches in diameter and 1½ inches through, and each sludge-cake weighs about 47 pounds, or each pressful about

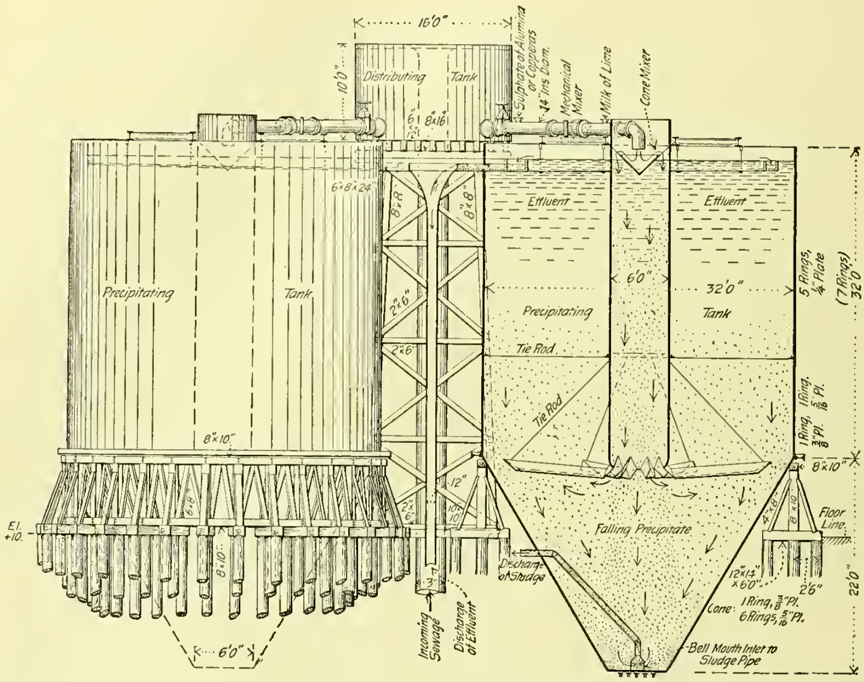


Fig. 116.—Elevation and Section of Receiving and Precipitating Tanks, World's Columbian Exposition.

2,350 pounds. The sludge is burned in an Engle garbage crematory, near by.

The plant was put in operation April 14, 1893, and so far as the record is available treated sewage as follows:

Month of May............	940,000	gallons	per	day.
" " June...........	1,630,000	"	"	"
First three weeks in July.	2,250,000	"	"	"

The cost of chemicals until July 1 was at the rate of about $8 per 1,000,000 gallons treated. The plant is operated in eight-hour shifts, an engineer, fireman, pressman, chemical man, and two laborers in the morning; the same, less the two laborers, in the afternoon; and again, less the laborers and pressman, at night.

The plant cost from $30,000 to $33,000, excluding the building. It was built under the direction of W. S. McHarg, Engineer of Water Supply, Sewerage, and Fire Protection of the Exposition, and is run

under the supervision of Allen Hazen, Chemist of the Lawrence Experiment Station of the Massachusetts State Board of Health.*

Purification Works Under Construction.

In addition to the works described, plants are known to be under construction as follows; Meriden, Connecticut, intermittent filtration, with Carrol Ph. Bassett, M. Am. Soc. C.E., engineer; Brockton, Massachusetts, intermittent filtration, F. H. Snow, engineer; Princeton, New Jersey, Professor C. M'Millan, engineer. There are also a number of places where plans of sewage disposal works have been prepared, but where no action has yet been taken towards beginning construction.

Plans have been prepared for the following towns in New York state, on which construction is likely to begin in the course of a year or two: The village of Far Rockaway, J. J. Powers, engineer; the Twenty-fourth Ward of the City of Brooklyn, Robert Van Buren, M. Am. Soc. C. E., chief engineer; the villages of Holly and Albion, Waldo and Dodgson, engineers, Geo. W. Rafter, M. Am. Soc. C. E., consulting engineer. There are also several public institutions in different parts of the United States where something has been done in the way of sewage purification plants, but which are not referred to for the reason that so far as known to the authors the plans do not involve anything of special interest over what has been already given.

* For additional information and illustrations see Eng. News, vol. xxx., p. 86 (Aug. 3, 1893).

APPENDICES.

APPENDIX I.

The following is the English Rivers Pollution Prevention Act of 1876, under the provisions of which the large number of purification works constructed in that country during the last fifteen years have been carried out.

(39 and 40 Vict. chap. 75.)

AN ACT for making further Provision for the Prevention of the Pollution of Rivers. (15th August, 1876.)

Whereas it is expedient to make further provision for the prevention of the pollution of rivers, and in particular to prevent the establishment of new sources of pollution:

Be it therefore enacted by the Queen's most Excellent Majesty, by and with the advice and consent of the Lords Spiritual and Temporal, and Commons, in this present Parliament assembled, and by the authority of the same, as follows:—

1. This Act may be cited for all purposes as the Rivers Pollution Prevention Act, 1876.

PART I.

SOLID MATTERS.

2. Every person who puts, or causes to be put or to fall, or knowingly permits to be put or to fall or to be carried into any stream, so as to either singly or in combination with other similar acts of the same or any other person to interfere with its due flow, or to pollute its waters, the solid refuse of any manufactory, manufacturing process or quarry, or any rubbish or cinders, or any other waste, or any putrid solid matter, shall be deemed to have committed an offence against this Act.

In proving interference with the due flow of any stream, or in proving the pollution of any stream, evidence may be given of repeated acts which together cause such interference or pollution, although each act taken by itself may not be sufficient for that purpose.

PART II.

SEWAGE POLLUTIONS.

3. Every person who causes to fall or flow or knowingly permits to fall or flow or to be carried into any stream any solid or liquid sewage matter, shall (subject as in this Act mentioned) be deemed to have committed an offence against this Act.

Where any sewage matter falls or flows or is carried into any stream along a channel used, constructed, or in process of construction at the date of the passing of this Act for the purpose of conveying such sewage matter, the person causing or knowingly permitting the sewage matter so to fall or flow or to be carried shall not be deemed to have committed an offence against this Act if he shows to the satisfaction of the court having cognizance of the case that he is using the best

practicable and available means to render harmless the sewage matter so falling or flowing or carried into the stream.

Where the Local Government Board are satisfied after local inquiry that further time ought to be granted to any sanitary authority which at the date of the passing of this Act is discharging sewage matter into any stream, or permitting it to be so discharged, by any such channel as aforesaid, for the purpose of enabling such authority to adopt the best practicable and available means for rendering harmless such sewage matter, the Local Government Board may by order declare that this section shall not, so far as regards the discharge of such sewage matter by such channel, be in operation until the expiration of a period to be limited in the order.

Any order made under this section may be from time to time renewed by the Local Government Board, subject to such conditions, if any, as they may see fit.

A person other than a sanitary authority shall not be guilty of an offence under this section in respect to the passing of sewage matter into a stream along a drain communicating with any sewer belonging to or under the control of any sanitary authority, provided he has the sanction of the sanitary authority for so doing.

PART III.

Manufacturing and Mining Pollutions.

4. Every person who causes to fall or flow or knowingly permits to fall or flow or to be carried into any stream any poisonous, noxious, or polluting liquid proceeding from any factory or manufacturing process, shall (subject as in this Act mentioned) be deemed to have committed an offence against this Act.

Where any such poisonous, noxious, or polluting liquid as aforesaid falls or flows or is carried into any stream along a channel used, constructed, or in process of construction at the date of the passing of this Act, or any new channel constructed in substitution thereof, and having its outfall at the same spot, for the purpose of conveying such liquid, the person causing, or knowingly permitting the poisonous, noxious, or polluting liquid so to fall or flow or to be carried, shall not be deemed to have committed an offence against this Act if he shows to the satisfaction of the court having cognizance of the case that he is using the best practicable and reasonably available means to render harmless the poisonous, noxious, or polluting liquid so falling or flowing or carried into the stream.

5. Every person who causes to fall or flow, or knowingly permits to fall or flow, or to be carried into any stream, any solid matter from any mine in such quantities as to prejudicially interfere with its due flow, or any poisonous, noxious, or polluting solid or liquid matter proceeding from any mine, other than water in the same condition as that in which it has been drained or raised from such mine, shall be deemed to have committed an offence against this Act, unless in the case of poisonous, noxious, or polluting matter he shows to the satisfaction of the court having cognizance of the case that he is using the best practicable and reasonably available means to render harmless the poisonous, noxious, or polluting matter so falling or flowing or carried into the stream.

6. Unless and until Parliament otherwise provides, the following enactment shall take effect, proceedings shall not be taken against any person under this part of this Act save by a sanitary authority, nor shall any such proceedings be taken without the consent of the Local Government Board: Provided, always, that if the sanitary authority, on the application of any person interested alleging an offence to have been committed, shall refuse to take proceedings, or apply for the consent by this section provided, the person so interested may apply to the Local Government Board, and if that Board, on inquiry, is of opinion that the sanitary authority should take proceedings, they may direct the sanitary authority accordingly, who shall thereupon commence proceedings.

The said Board, in giving or withholding their consent, shall have regard to the industrial interests involved in the case, and to the circumstances and requirements of the locality.

The said Board shall not give their consent to proceedings by the sanitary authority of any district which is the seat of any manufacturing industry, unless they are satisfied, after due inquiry, that means for rendering harmless the poisonous, noxious, or polluting liquids proceeding from the processes of such manufactures are reasonably practicable and available under all the

circumstances of the case, and that no material injury will be inflicted by such proceedings on the interests of such industry.

Auy person within such district as aforesaid, against whom proceedings are proposed to be taken under this part of this Act, shall, notwithstanding any consent of the Local Government Board, be at liberty to object before the sanitary authority to such proceedings being taken, and such authority shall, if required in writing by such person, afford him an opportunity of being heard against such proceedings being taken, so far as the same relate to his works or manufacturing processes. The sanitary authority shall thereupon allow such person to be heard by himself, agents, and witnesses, and after inquiry, such authority shall determine, having regard to all the considerations to which the Local Government Board are by this section directed to have regard, whether such proceedings as aforesaid shall or shall not be taken; and where any such sanitary authority has taken proceedings under this Act, it shall not be competent to other sanitary authorities to take proceedings under this Act till the party against whom such proceedings are intended shall have failed in reasonable time to carry out the order of any competent court under this Act.

PART IV.

Administration.

7. Every sanitary or other local authority having sewers under their control shall give facilities for enabling manufaeturers within their district to carry the liquids proceeding from their factories or manufacturing processes into such sewers:

Provided, that this section shall not extend to compel any sanitary or other local authority to admit into their sewers, any liquid which would prejudicially affect such sewers, or the disposal by sale, application to land, or otherwise, of the sewage matters conveyed along such sewers, or which would from its temperature or otherwise be injurious in a sanitary point of view: Provided, also, that no sanitary authority shall be required to give such facilities as aforesaid where the sewers of such authority are only sufficient for the requirements of their district, nor where such facilities would interfere with any order of any court of competent jurisdiction respecting the sewage of such authority.

8. Every sanitary authority shall, subject to the restrictions in this Act contained, have power to enforce the provisions of this Act in relation to any stream being within or passing through or by any part of their district, and for that purpose to institute proceedings in respect of any offence against this Act which causes interference with the due flow within their district of any such stream, against any other sanitary authority or person, whether such offence is committed within or without the district of the first-named sanitary authority.

Any expenses incurred by a sanitary authority in the execution of this Act shall be payable as if they were expenses properly incurred by that authority in the execution of the Public Health Act, 1875.

Proceedings may also, subject to the restrictions in this Act contained, be instituted in respect of any offence against this Act by any person aggrieved by the commission of such offence.

9. The Conservancy Board constituted under the Lee Conservancy Act, 1868, shall, within the area of their jurisdiction, have, to the exclusion of any other authority, the powers for enforcing the provisions of this Act which sanitary authorities have under this Act.

The said Conservancy Board may also enforce the provisions of the Lee Conservancy Act, 1868, under the head or division, "Protectiou of Water," by application to the county court having jurisdiction in the place in which any offence is committed against those provisions; and such court may by summary order require any person to abstain from the commission of any such offence, and the provisions of this Act with respect to summary orders of county courts and appeal therefrom shall apply accordingly.

LEGAL PROCEEDINGS. SAVING CLAUSES. DEFINITIONS.

(1) Legal Proceedings.

10. The county court having jurisdiction in the place where any offence against this Act is committed may by summary order require any person to abstain from the commission of such offence, and where such offence consists in default to perform a duty under this Act may require him to

perform such duty in manner in the said order specified; the court may insert in any order such conditions as to the time or mode of action as it may think just, and may suspend or rescind any order on such undertaking being given or condition being performed as it may think just, and generally may give such directions for carrying into effect any order as to the court seems meet. Previous to granting such order, the court may, if it think fit, remit to skilled parties to report on the "best practicable and available means," and the nature and cost of the works and apparatus required, who shall in all cases take into consideration the reasonableness of the expense involved in their report.

Any person making default in complying with any requirement of an order of a county court made in pursuance of this section shall pay to the person complaining, or such other person as the court may direct, such sum, not exceeding fifty pounds a day for every day during which he is in default, as the court may order; and such penalty shall be enforced in the same manner as any debt adjudged to be due by the court; moreover, if any person so in default persists in disobeying any requirement of any such order for a period of not less than a month, or such other period less than a month as may be prescribed by such order, the court may in addition to any penalty it may impose appoint any person or persons to carry into effect such order, and all expenses incurred by any such person or persons to such amount as may be allowed by the county court shall be deemed to be a debt due from the person or persons executing such order, and may be recovered accordingly in the county court.

11. If either party in any proceedings before the county court under this Act feels aggrieved by the decision of the court in point of law, or on the merits, or in respect of the admission or rejection of any evidence, he may appeal from that decision to the High Court of Justice.

The appeal shall be in the form of a special case to be agreed upon by both parties or their attorneys, and, if they cannot agree, to be settled by the judge of the county court upon the application of the parties or their attorneys.

The court of appeal may draw any inferences from the facts stated in the case that a jury might draw from facts stated by witnesses.

Subject to the provisions of this section, all the enactments, rules, and orders relating to proceedings in actions in county courts, and to enforcing judgments in county courts and appeals from decisions of the county court judges and to the conditions of such appeals, shall apply to all proceedings under this Act, and to an appeal from such action, in the same manner as if such action and appeal related to a matter within the ordinary jurisdiction of the court.

Any plaint entered in a county court under this Act may be removed into the High Court of Justice by leave of any judge of the said High Court, if it appears to such judge desirable in the interests of justice that such case should be tried in the first instance in the High Court of Justice, and not in a county court, and on such terms as to security for and payment of costs, and such other terms (if any) as such judge may think fit.

12. A certificate granted by an inspector of proper qualifications, appointed for the purposes of this Act by the Local Government Board to the effect that the means used for rendering harmless any sewage matter or poisonous, noxious, or polluting solid or liquid matter falling or flowing or carried into any stream, are the best or only practicable and available means under the circumstances of the particular case, shall in all courts and all proceedings under this Act be conclusive evidence of the fact; such certificate shall continue in force for a period to be named therein, not exceeding two years, and at the expiration of that period may be renewed for the like or any less period.

All expenses incurred in or about obtaining a certificate under this section shall be paid by the applicant for the same.

Any person aggrieved by the grant or the withholding of a certificate under this section may appeal to the Local Government Board against the decision of the Inspector; and the Board may either confirm, reverse, or modify his decision, and may make such order as to the party or parties by whom the costs of the appeal are to be borne as to the said Board may appear just.

13. Proceedings shall not be taken under this Act against any person for any offence against the provisions of Parts II. and III. of this Act until the expiration of twelve months after the passing of this Act; nor shall proceedings in any case be taken under this Act for any offence against this Act until the expiration of two months after written notice of the intention to take such proceedings has been given to the offender, nor shall proceedings under this Act be taken for any offence against this Act until the expiration of two months after written notice of the inten-

tion to take such proceedings has been given to the offender, nor shall proceedings under this Act be taken for any offence against this Act while other proceedings in relation to such offence are pending.

14. The Local Government Board may make orders as to the costs incurred by them in relation to inquiries instituted by them under this Act, and as to the parties by whom such costs shall be borne; and every such order and every order for the payment of costs made by the said Board under section twelve of this Act may be made a rule of Her Majesty's High Court of Justice.

15. Inspectors of the Local Government Board shall, for the purposes of any inquiry directed by the Board under this Act, have in relation to witnesses and their examination, the production of papers and accounts, and the inspection of places and matters required to be inspected, similar powers to those which the inspectors of the said Board have under the Public Health Act, 1875, for the purposes of that Act.

(2) Saving Clauses.

16. The powers given by this Act shall not be deemed to prejudice or affect any other rights or powers now existing or vested in any person or persons by Act of Parliament, law, or custom, and such other rights or powers may be exercised in the same manner as if this Act had not passed; and nothing in this Act shall legalize any act or default which would but for this Act be deemed to be a nuisance or otherwise contrary to law: Provided, nevertheless, that in any proceedings for enforcing against any person such rights or powers the court before which such proceedings are pending shall take into consideration any certificate granted to such person under this Act.

17. This Act shall not apply to or affect the lawful exercise of any rights of impounding or diverting water.

18. Nothing in or done under this Act shall extend to interfere with, take away, abridge, or prejudicially affect any right, power, authority, jurisdiction, or privilege given by "The Thames Conservancy Acts, 1857 and 1864," or by "The Thames Navigation Act, 1866," or by the Lee Conservancy Act, 1868, or any Act or Acts extending or amending the said Acts or either of them, or affect any outfall or other works of the Metropolitan Board of Works (although beyond the metropolis) executed under the Metropolis Management Act, 1855, and the Acts amending or extending the same, or take away, abridge, or prejudicially affect any right, power, authority, jurisdiction, or privilege of the Metropolitan Board of Works.

19. Where any local authority, or any urban or rural sanitary authority, has been empowered or required by any Act of Parliament to carry any sewage into the sea, or any tidal water, nothing done by such authority in pursuance of such enactment shall be deemed to be an offence against this Act.

(3) Definitions.

20. In this Act, if not inconsistent with the context, the following terms have the meanings hereinafter respectively assigned to them; that is to say,—

"Person" includes any body of persons, whether corporate or unincorporate.

"Stream" includes the sea to such extent, and tidal waters to such point, as may, after local inquiry and on sanitary grounds, be determined by the Local Government Board, by order published in the London Gazette. Save as aforesaid, it includes rivers, streams, canals, lakes, and water-courses, other than water-courses at the passing of this Act mainly used as sewers, and emptying directly into the sea, or tidal waters which have not been determined to be streams within the meaning of this Act by such order as aforesaid.

"Solid matter" shall not include particles of matter in suspension in water.

"Polluting" shall not include innocuous discoloration.

"Sanitary authority" means—

In the metropolis, as defined by the Metropolis Management Act, 1855, any local authority acting in the execution of the Nuisance Removal for England Act, 1855, and the Acts amending the same.

Elsewhere in England, any urban or rural sanitary authority acting in the execution of the Public Health Act, 1875.

The application of the Act to Scotland and Ireland is omitted, as consisting chiefly in definitions and explanations, and as being, therefore, irrelevant to our circumstances.

APPENDIX II.

AN ACT to confer upon the State Board of Health power to protect from contamination, by suitable regulations, the water supplies of the State and their sources. Passed June 13, 1885; chapter 543, Laws of 1885.

The People of the State of New York, represented in Senate and Assembly, do enact as follows:

SECTION 1. The State Board of Health is hereby authorized and empowered to make rules and regulations for protecting from contamination any and all public supplies of potable waters and their sources within this State. Provided, however, any such rule or regulation shall not be operative in any county until the county judge of that county shall approve the same.

SECT. 2. The said State Board of Health shall also have power, and it shall be its duty: 1. To publish once a week, for at least six consecutive weeks, all such rules and regulations as it shall have made concerning the contamination of any sub-soil waters, springs, streams, lakes, ponds, reservoirs, or other bodies of water contributing to the potable water supply of any municipality within this State, such publication to be made in one or more newspapers published in the county in which the waters affected by such regulations are located. The cost of publishing the regulations of the State Board of Health, as above provided, shall be paid by the corporation or municipality benefited by the protection of the water supply, concerning which the rules are made. 2. To impose penalties for the violation of, or the non-compliance with, their rules and regulations, not exceeding two hundred dollars in any one case.

SECT. 3. The officer or board having by law the management and control of the potable water supply of any municipality, in all cases where the said municipality derives its water supply in whole or in part from any sub-soil water, springs, streams, lakes, ponds, reservoirs, or other waters concerning which the State Board of Health shall make any rule or regulation, is hereby authorized and empowered to make such inspection of the sources of said water supply as said officer or board may deem advisable to secure the said water supply from any defilement, and to ascertain whether or not the rules and regulations made by the State Board of Health are complied with.

SECT. 4. In case such inspection shall disclose the violation by any person or persons of any of the rules or regulations of the said State Board of Health relating to the sources of said water supply, the officer or board mentioned in section three of this act shall serve or cause to be served a copy of the said rules and regulations, accompanied by a notice specifying the rule or regulation claimed to have been violated, upon the said person or persons violating such rules or regulations. If the person or persons so served do not immediately comply with the said regulation, the said officer or board having charge of the water supply of the municipality affected thereby shall notify the State Board of Health of the violation of its rules; the State Board of Health shall thereupon examine into the said violation, and if the party complained of is found to have actually violated any of the said regulations, the Secretary of the State Board of Health shall order the local board of health having jurisdiction thereof to convene and enforce obedience to the said regulation.

SECT. 5. In case any local board of health having jurisdiction thereof fails to enforce the order of the Secretary of the State Board of Health within ten days after the receipt of a notification so to do, as provided in the last section, the corporation furnishing the water supply, or the municipality deriving its water supply from the waters for the sanitary protection of which such rules have been made, is hereby authorized and empowered to maintain an action in a court of record and which shall be tried in the county in which the cause of action arose against the person or persons violating the said rules for recovery of the penalty therein provided.

SECT. 6. Every person who shall wilfully violate or refuse to obey any rule or regulation made and published by the State Board of Health, and approved pursuant to the provisions of this act, shall be guilty of a misdemeanor, and on a conviction thereof shall be subject to a fine or imprisonment, or both, at the discretion of the court, such fine not to exceed three hundred dollars, nor such imprisonment six months. But the recovery of a penalty in a civil action, as provided in section five of this act, and criminal prosecution and conviction under the provisions of this section, shall not be had for the same offense.

SECT. 7. When the State Board of Health shall, for the protection of a water supply from contamination, make regulations, the execution of which will require the providing of some public means of removal or purification of sewage, the municipality or corporation owning the water-works benefited thereby shall, at its own expense, construct and maintain such works or means for sewage disposal, as shall be approved by the State Board of Health.*

SECT. 8. The State Board of Health, any local board of health, or any municipality or corporation furnishing water, may cause the affidavit of the printer, publisher, or proprietor of any newspaper publishing the rules and regulations as provided by the second section of this act, to be filed with such rules as published in the clerk's office of the county in which the municipality or corporation furnishing the water supply in any case may be situated or located, and such affidavit and rules, or duly certified copies thereof, shall be deemed conclusive evidence of due publication and of all the facts therein stated in all courts and in all proceedings or prosecutions under the provisions of this act.

SECT. 9. All acts or parts of acts inconsistent with the provisions of this act are hereby repealed.

SECT. 10. This act shall take effect immediately.

APPENDIX III.

The following is the first set of Rules for the sanitary protection of water-sheds established under the New York State Act:

RULES AND REGULATIONS for the Sanitary Protection of the Waters of Hemlock Lake, the Public Potable Water Supply of the City of Rochester.

Privies adjacent to the Lake.

RULE I.

SECTION A. All houses, cottages, tenements, tents, camp and picnic grounds, adjacent to the shores of Hemlock lake, shall be provided with, at least, one privy, which shall be placed upon the ground, without any vault beneath it, and shall be so constructed that metallic pails, fifteen inches high by fourteen inches in diameter, can be placed under the seats and be frequently and easily removed with their contents.

SECTION B. The privies shall be so located that access to them from the lake may be had, for the purpose of facilitating the removal of the pails.

SECTION C. Occupants of the premises should daily add earth or ashes to the contents of the pails, as a deodorizer and absorbent.

SECTION D. The owners and occupants shall also exercise due care and oversight of the pails used in the privies.

SECTION E. When any privy is to be used in winter as well as summer it shall be so located and arranged that the pail may be replaced by a water-tight box or trough resting on solid runners or small wheels, and having a staple by which it may be drawn out from under the seat, or be otherwise so arranged that when the box is sufficiently filled, it may be taken from under the privy and the contents emptied in some safe place, where they cannot possibly be washed into the lake or into any stream running into the lake, or into any well or spring. Ashes should daily be thrown into the privy box as a deodorizer.

SECTION F. No owner or occupant shall have upon their premises any privy vault of any kind situated within two hundred feet of the shore of Hemlock lake.

RULE II.

SECTION A. The city of Rochester shall furnish a sufficient number of pails, for the use of each privy situated within two hundred feet of the shore of Hemlock lake, and shall cause the pails to be placed under the seats, and to be removed, emptied, cleansed and disinfected as often as may be necessary to insure that they are kept in good sanitary condition.

* In 1890 this section was amended, throwing even more completely the expense of protection upon the municipality.

SECTION B. When a full pail is removed from a privy, its place shall be immediately supplied by an empty one.

SECTION C. The pails shall be made of metal, and shall be fifteen inches high by fourteen inches in diameter, outside measurement. They shall be provided with covers, to be used during removal.

SECTION D. The removal of the pails from the privies shall be conducted in such a manner as to cause as little inconvenience or annoyance to the occupants of the premises as is compatible with proper management of the business.

SECTION E. The contents of the pails shall be removed by the city of Rochester to some point below the foot of the lake, and be so treated and disposed of as to cause no nuisance nor danger to the public health.

Privies near Streams, Springs or Water-courses on Hemlock Lake Water-shed.

RULE III.

SECTION A. No privy shall be located within thirty feet of any stream, spring or dry water-course, the water from which, when running, empties eventually into Hemlock lake.

RULE IV.

SECTION A. Any privy situated within fifty feet of any stream, spring or dry water-course, on the water-shed of Hemlock lake, or within fifty feet of the bank of any ravine on this water-shed, shall be constructed without a vault, and shall have under the seats half barrels, tubs, pails, or water-tight boxes or troughs arranged to be easily and frequently removed, emptied, cleansed and returned to their place, under the privy seats. Ashes or dry earth should daily be used in these privies as a deodorizer and absorbent.

RULE V.

SECTION A. The owners or occupants of premises having privies with tubs, pails or boxes, shall cause the contents to be removed and the receptacle to be cleaned as often as is necessary to keep the privy in good sanitary condition.

SECTION B. The contents of the said privies shall be disposed of in such a manner that they can by no possibility be washed into any stream, dry water-course, ravine, spring or well, either over the surface or through the sub-soil, and the excremental matter shall be so placed as not to cause an offensive nuisance.

RULE VI.

SECTION A. If, owing to the porous character of the soil, the height and flow of the surface or sub-soil waters, the steepness of the slopes, or other conditions of the locality, it shall be the judgment of the local board of health, or of the State Board, that the excremental matter from any privy may be washed on the surface or through the soil into some neighboring spring or water-course, then, after due notice to the owners or occupants of these premises, their privy shall be made to conform to the rules governing privies situated within fifty feet of water-courses.

Garbage.

RULE VII.

SECTION A. The owners or occupants of all houses, cottages, tenements, tents, camp and picnic grounds, within two hundred feet of Hemlock lake, shall place all garbage produced on their premises in such receptacles as may be provided therefor by the city of Rochester.

SECTION B. No garbage shall be thrown into the lake, or upon the ground within two hundred feet of the lake, nor shall it be thrown upon any spot where it may possibly be washed into the lake.

Rule VIII.

Section A. The city of Rochester shall provide proper receptacles for receiving the garbage produced on all premises within two hundred feet of Hemlock lake, and shall cause the same to be removed and emptied as often as may be necessary.

Rule IX.

Section A. All house slops, and sink and laundry water, produced on premises adjacent to Hemlock lake, shall be thrown upon the surface of the ground, and distributed so as to prevent concentration and saturation at one spot, but no such polluted water shall be thrown upon the ground within one hundred feet of the lake shore, or as near that limit as the depth of the lot will permit, nor into, nor near any spring, water-course or ravine.

Rule X.

Section A. No garbage or house slops, sink or laundry water shall be discharged into any stream, spring or dry water-course, on any part of the water-shed of Hemlock lake, nor shall any such putrescible or polluted waters be thrown upon the ground or into it, where they may pollute any spring, stream or water-course on this water-shed.

Animal Manures.

Rule XI.

Section A. All stables situated within two hundred feet of Hemlock lake shall be provided by their owners or occupants with a tight and well-covered bin or box, in which all manures shall be placed, and from which it shall be removed as often as cleanliness may require.

Rule XII.

Section A. No stable, pig-sty, hen-house, barn-yard, hog-yard, hitching or standing place for horses, or other place where animal manure accumulates, shall be so constructed or located that the manure from it may wash into the lake or into any stream, spring or dry water-course running into the lake.

Manufacturing Waste.

Rule XIII.

Section A. No waste products, putrescible matters or polluted waters from any slaughter-houses, cheese factories, wine or beer vaults, cider-mills, tanneries, saw-mills or other manufactories shall be allowed to drain or wash into any stream, spring or dry water-course, or any part of Hemlock lake water-shed, or into the lake.

Animal and Vegetable Matters.

Rule XIV.

Section A. No dead animal, bird or fish, nor any filthy or impure matter, nor any decayed fruit, vegetable substances, leaves, saw-dust, roots, branches or trunks of trees in any condition of their growth or decay shall be thrown into Hemlock lake, or so placed by any person that they shall wash into the lake, nor shall they be thrown into any spring, stream or water-course running into the lake.

Washing Sheep or Animals.

RULE XV.

SECTION A. No sheep or other animals shall be washed in Hemlock lake, or in any influent stream within half a mile of the lake, nor shall any diseased sheep be washed in any spring, pond or stream on the water-shed of Hemlock lake.

RULE XVI.

SECTION A. In accordance with chapter 543 of the laws of 1885, a penalty of $50 is hereby imposed upon any person or persons guilty of violation of or non-compliance with any of the above given mandatory rules or regulations, to be recovered under said act.

Approved by order of the State Board of Health.

APPENDIX IV.

THE following is the Massachusetts Act for the Protection of Inland Waters as Amended in 1888:

AN ACT to protect the Purity of Inland Waters, and to require Consultation with the State Board of Health regarding the Establishment of Systems of Water Supply, Drainage and Sewerage.

Be it enacted, etc., as follows:

SECT. 1. The state board of health shall have the general oversight and care of all inland waters, and shall be furnished with maps, plans and documents suitable for this purpose, and records of all its doings in relation thereto shall be kept. It may employ such engineers and clerks and other assistants as it may deem necessary: *provided*, that no contracts or other acts which involve the payment of money from the treasury of the Commonwealth shall be made or done without an appropriation expressly made therefor by the general court. It shall annually on or before the tenth day of January report to the general court its doings in the preceding year, and at the same time submit estimates of the sums required to meet the expenses of said board in relation to the care and oversight of inland waters for the ensuing year, and it shall also recommend legislation and suitable plans for such systems of main sewers as it may deem necessary for the preservation of the public health, and for the purification and prevention of pollution of the ponds, streams and inland waters of the Commonwealth.

SECT. 2. Said board shall from time to time, as it may deem expedient, cause examinations of the said waters to be made for the purpose of ascertaining whether the same are adapted for use as sources of domestic water supplies or are in a condition likely to impair the interests of the public or persons lawfully using the same, or imperil the public health. It shall recommend measures for prevention of the pollution of such waters, and for removal of substances and causes of every kind which may be liable to cause pollution thereof, in order to protect and develop the rights and property of the Commonwealth therein and to protect the public health. It shall have authority to conduct experiments to determine the best practicable methods of purification of drainage and sewage or disposal of the same. For the purpose aforesaid it may employ such expert assistance as may be necessary.

SECT. 3. It shall from time to time consult with and advise the authorities of cities and towns, or with corporations, firms or individuals either already having or intending to introduce systems of water supply, drainage or sewerage, as to the most appropriate source of supply, the best practicable method of assuring the purity thereof or of disposing of their drainage or sewage, having regard to the present and prospective needs and interests of other cities, towns, corporations, firms or individuals which may be affected thereby. It shall also from time to time consult with and advise persons or corporations engaged or intending to engage in any manufacturing or other

business, drainage or sewage from which may tend to cause the pollution of any inland water, as to the best practicable method of preventing such pollution by the interception, disposal or purification of such drainage or sewage: *provided*, that no person shall be compelled to bear the expense of such consultation or advice, or of experiments made for the purposes of this act. All such authorities, corporations, firms and individuals are hereby required to give notice to said board of their intentions in the premises, and to submit for its advice outlines of their proposed plans or schemes in relation to water supply and disposal of drainage and sewage, *and all petitions to the legislature for authority to introduce a system of water supply, drainage or sewerage shall be accompanied by a copy of the recommendation and advice of the said board thereon.* Said board shall bring to the notice of the attorney-general all instances which may come to its knowledge of omission to comply with existing laws respecting the pollution of water supplies and inland waters, and shall annually report to the legislature any specific cases not covered by the provisions of existing laws, which in its opinion call for further legislation.

SECT. 4. In this act the term "drainage" refers to rainfall, surface and subsoil water only, and "sewage" refers to domestic and manufacturing filth and refuse.

SECT. 5. Chapter two hundred and seventy-four of the acts of the year eighteen hundred and eighty-six is hereby repealed, but nothing in this act shall be construed to affect the expenditures authorized under chapter thirty of the resolves of the year eighteen hundred and eighty-eight.

SECT. 6. This act shall take effect upon its passage. (Approved May 18, 1888.)

APPENDIX V.

THE city of Passaic, New Jersey, having proposed to turn its outfall sewer into the Passaic river at a point about 4 miles above the Newark Water-works intake, the city of Newark sought to restrain Passaic from such discharge.

The following is the Chancellor's decision on the original application as rendered in 1889:

NEWARK AQUEDUCT BOARD *v.* CITY OF PASSAIC.

(*Court of Chancery of New Jersey.* July 22, 1889.)

NUISANCE—POLLUTION OF STREAM—INJUNCTION.

A corporation called the "Newark Aqueduct Company" was authorized by statute to use springs "and other sources of water," to supply the inhabitants of Newark with water, and to take such sources of water supply by condemnation. In 1860 the city of Newark was empowered, by act of the legislature, to purchase the property of the Newark Aqueduct Company, and to make use of its sources of water supply, and "any other sources," taking by condemnation, if necessary. The complainant, the Newark Aqueduct Board, is a public body, charged with the management of Newark's water supply, and is empowered by statute to maintain suits in equity or at law "for any injury or trespass or nuisance, done or caused, or procured to be done, to the water-courses, pipes, machinery, or any apparatus belonging to or connected with any part of the works, or for any improper use or waste of the water." In 1867 the complainant purchased for the city of Newark land bordering upon the Passaic river, a tidal stream, and upon the land thus purchased constructed a pumping station, and, abandoning all other sources of water supply, for several years has taken large quantities of water, for domestic and other uses, by the inhabitants of Newark, from the Passaic river. The city of Passaic, situate upon the same river, about four miles above the complainant's pumping station, proposes to discharge its main sewer into the tidal water of the river. The complainant alleges that such discharge will materially pollute the water of the river, and thereby create a nuisance injurious to it, and by bill, in its own name and behalf, seeks an injunction to restrain the proposed discharge of sewage. *Held*, (*a*) that the

water of the Passaic river, where the tide ebbs and flows, belongs to the state, for uses common to all its citizens; (*b*) that the city of Newark has no special rights in that water, either by reason of its riparian ownership on the river, or by grant from the state, which may be injured by the apprehended nuisance, and enable the complainant, by showing an apprehended injury, distinct from that which will be suffered by the other inhabitants of this state, to maintain its individual suit to restrain the nuisance; (*c*) that, at best, such special rights have not been established by adjudication in this state; (*d*) that the complainant is not in position to ask for a preliminary injunction when the right on which it founds its claim is, as a matter of law, unsettled; (*e*) that the proceeding in equity to restrain a public nuisance is by information by the attorney general; (*f*) that the statutory authority to the complainant to maintain a suit in equity for nuisance to water-courses connected with its works did not constitute it a public agent to sue to restrain a public nuisance, but merely clothed it with power to sue, as an individual might, for the protection of private property; (*g*) that an injunction to restrain a nuisance will issue only in cases where the fact of nuisance is made out upon determinate and satisfactory evidence, and that, if the evidence be conflicting, and the injury be doubtful, that will constitute a ground for withholding the injunction, and, if the nuisance be merely apprehended, it must appear that apprehension of material and irreparable injury is well grounded, upon a state of facts which show the danger to be real and immediate; (*h*) that such conditions of fact do not appear in this case.

(*Syllabus by the Court.*)

On order to show cause why an injunction should not issue restraining the discharge of sewage into the Passaic river.

E. L. Price and *Thomas N. McCarter*, for the order. *C. P. Rust* and *J. W. Griggs*, *contra.*

McGill, C. The complainant is a corporate body, composed of commissioners who are from time to time elected by the legal voters of the city of Newark, and is charged by statute with the control and management of the supply of "pure and wholesome water" for that city. Among other powers conferred upon it is authority to maintain a suit at law or in equity for injury, trespass, or nuisance to water-courses and apparatus connected with the water-works which are confided to its care. P. L. 1860, p. 442. By an act of the legislature passed in the year 1800, a corporation known as the "Newark Aqueduct Company" was incorporated by the name "The President and Directors of the Newark Aqueduct Company," for the purpose of furnishing water to the inhabitants of Newark, and was empowered to make use of any spring or springs that it might think necessary to use for the purpose of obtaining a supply of water. P. L. 1800, p. 10. By a supplement to that act of incorporation, which was approved February 17, 1857, (P. L. 19,) it was recited that the city of Newark was rapidly increasing in population, and that many additional springs and "other sources of water" were to be found in the vicinity of Newark which could be made available by the company, but which the company could not purchase through "private negotiations," and power was therefore given it to search for water and to take by condemnation. By the act of the legislature approved March 20, 1860, (P. L. 442,) above referred to. the city of Newark was authorized to buy the property of the aqueduct company, and thereafter to take sufficient water to supply the city of Newark from the sources of supply which the aqueduct company then used or was empowered to use, and "from any other sources;" and in order to make other sources of water supply available a method of condemning water-rights was provided. In pursuance of the authority thus conferred, the mayor and common council of the city of Newark purchased the plant of the aqueduct company. In 1867 the population of Newark had so largely increased, and the demand for a greater supply of water had become so urgent, that the complainant purchased about 12 acres of land, having a frontage of about 2,000 feet upon the west bank of the Passaic river, about a mile above the village of Belleville, upon which, at considerable cost, it caused a pumping station to be built, from which water has since been pumped from the Passaic river to a large receiving reservoir constructed upon high ground about a mile from the pumping station, and from thence distributed to the city of Newark, two miles distant, and to adjoining towns, for domestic and other uses. In 1869, after the completion of the pumping station and the receiving reservoir, all sources of water supply, other than the Passaic river, were abandoned. In the acquisition of this plant the city of Newark expended upwards of $1,000,000. The water it takes from the river averages 13,000,000 of gallons daily, and is distributed to nearly 200,000 persons, who, by paying water-rates, confer a large revenue to the maintenance of the water-works. and the payment of the interest upon bonds that were issued by the city of Newark for their construction.

The tide ebbs and flows in the Passaic river at the point at which Newark's supply of water is taken, and for a distance of about five miles above that point, and one mile above the city of Passaic, and within the same limits, the river is in fact navigable. The city of Passaic, having a population of upwards of 10,000 persons, is situated upon the west bank of the river, four miles above the intake of the water for Newark. It was incorporated in 1873, (P. L. 1873, p. 484,) and in 1875 (P. L. 1875, p. 570) was authorized to cause sewers and drains to be constructed in any part of the city. In pursuance of this power it has lately, against the complainant's protest, contracted with the other defendants herein to construct a main sewer, with several lateral sewers emptying into it, and to so build the main sewer that its contents will be discharged into the Passaic river. The plans for the proposed construction contemplate sewers aggregating 3,650 feet in length, and the drainage of 110 dwelling-houses, containing 1,126 inhabitants, shops, stores, and manufactories, in which 113 people are employed, and a public school attended by about 400 pupils. The portion of the city in which these drains are to be located is rapidly building up and increasing in population. The sewers will not receive the surface or rain water, but will be cleared by means of flush-tanks, and, as it is estimated, will daily discharge into the Passaic river 60,000 gallons of filth from privies, sinks, and factories. Health statistics exhibit that during the past year 20 per cent. of the deaths in Passaic were caused by typhoid and scarlet fevers, diphtheria, cholera infantum, and dysentery, and it is insisted that the foul *excreta* of patients suffering with those diseases will be carried into the Passaic river through the proposed sewers, and therefrom germs of those diseases will be pumped to the complainant's distributing reservoir, and be distributed to a large population, endangering its health. To secure the prohibition of the proposed discharge of these sewers into the Passaic river is the object of this suit.

The complainant takes the position, in the first place, that the proposed sewage will pollute the waters that it supplies to Newark and other municipalities, and will thereby create a nuisance especially injurious to the complainant; and, in the second place, if it should be determined that the complainant will not sustain a special and distinct injury, it is nevertheless empowered by special statutory authority to maintain this suit, if injury will result to it at all, though it be merely in common with the remainder of the public. To this the defendants reply—*First*, that the complainant has no right in the waters of the Passaic river which is not common to all citizens of this state, and that an injury to such a right cannot result in such a special and peculiar injury that will enable the complainant to maintain this suit in its own name; *second*, that in absence of such special injury it has no authority to maintain this suit; *third*, that if, under the legislation from which it derives its powers, the complainant has obtained a distinct right to the water of the Passaic. such right does not clearly appear, and should be established at law before the issuance of the injunction sought; and, *fourth*, that, in point of fact, the proposed discharge of the sewage will not pollute or otherwise injuriously affect the waters of the Passaic at the Newark intake.

It is well established that the title to navigable tide-water and to lands under navigable tide-water is in the state for the support of rights therein which are common to the entire public, such as the rights of navigation and fishing. Without express grant from the sovereign, no individual can obtain special rights in either the water itself or in the land under it. Riparian owners have no special rights in navigable streams in which the tide ebbs and flows by reason of adjacency to such stream, other than alluvion and dereliction. The rights common to the public are enjoyed by the riparian owner in common with others. All that he gains by adjacency to the water, in addition to the contingent rights by alluvion and dereliction, is convenience in the enjoyment of the common rights. Stevens v. Railroad Co., 34 N. J. Law, 532. The rule is different with respect to the riparian owner on a navigable stream in which the tide does not ebb and flow. There his title extends to the land under water to the middle of the stream, and to such use of the water as will not work injury to the rights of other riparian owners, or be materially detrimental to the public easement of navigation. Attorney General v. Railroad Co., 27 N. J. Eq. 1, 8, 638; Cobb v. Davenport, 32 N. J. Law, 369.

As the Passaic river at Newark's water intake is a tidal stream, that city has no special right in the water of the river in virtue of its riparian ownership, nor can I see how it can claim such right under the legislation to which I have referred. It is obvious that the legislature had in view the taking of water sources by condemnation, and that it did not contemplate a grant of any part of the public domain. The act of 1800 authorizes the use of springs by the aqueduct company. The act of 1857 extended the company's power of condemnation to additional springs and "other sources," and the act of 1860 gave similar powers to the complainant respecting all sources of its

water supply. No words indicative of an intention to grant public rights were used. The rule is well settled that general and indefinite words in a statute will not pass any prerogative, right, title, or interest of the sovereign. In Trustees v. City of Trenton, 30 N. J. Eq. 667, 683, Mr. Justice DEPUE says: "The common-law doctrine is that where the king has any prerogative, right, title, or interest, and the statute is general, he shall not be barred of them by the general words of the act, for the king shall not be bound unless the statute is made by express words to extend to him. Magdalen College Case, 11 Coke, 74; Willion v. Berkley, 1 Plow. 239; Bac. Abr. tit. 'Statute' (E). Independently of any doctrine founded on the notion of prerogative, the same construction ought to prevail, founded upon the legislative intent. Where the government is not expressly or by necessary implication included, it ought to be clear from the nature of the mischiefs to be reached, or the language used, that the government itself was in contemplation of the legislature, before a court of law would be authorized to put a construction on a statute which would affect its rights." The same judge in his charge to the jury in Stevens v. Railroad Co., as reported in 34 N. J. Law, 534, made use of this language: "The distinction between the grant of a mere franchise and a grant of a portion of the public domain is broadly marked. With respect to the latter, the rule is invariably adhered to that, in cases of doubt, the grant is to be construed in favor of the state, and most strongly against the grantee, who will take nothing not clearly given him by the grant. * * * An intent to alienate any portion of them without any consideration will not, in the absence of a formal grant, in express words, be implied, except upon the clearest necessity to effectuate the purpose of the legislature in investing the grantee with public franchises." In the same case in the court of errors and appeals (34 N. J. Law, 553) Chief Justice BEASLEY says: "The state is never presumed to have parted with any part of its property in the absence of conclusive proof of an intention to do so. Such proof must exist either in express terms or in necessary implications. I shall not cite authorities to sustain so familiar a proposition." State v. Bentley, 23 N. J. Laws, 538; Proprietors of Bridges v. Improvement Co., 13 N. J. Eq. 94; Water Com'rs v. Hudson City, Id. 420; Townsend v. Brown, 24 N. J. Law, 87; Banking Co. v. Railroad Co., 16 N. J. Eq. 419, 436; Endl. Interp. St. § 354.

Although it may be proper in some measure to relax the strict application of this rule in the case of a public body created essentially for a public purpose, like the complainant before me, yet, even there, there must be some manifestation of the legislative intent to grant public rights. I have been referred to other legislation, having for its object the prevention of the pollution of the waters of the Passaic within the boundaries of the counties of Essex and Hudson, (P. L. 1873, p. 683,) as indicative of legislative recognition of right in the complainant to take water from the Passaic where the tide ebbs and flows; but, in view of the fact that previous to that legislation the legislature expressly authorized the city of Jersey City (P. L. 1852, p. 419) and the Harrison Aqueduct Company (P. L. 1864, p. 754) and possibly other corporations to take the Passaic water at the locality indicated, the legislation referred to may properly be regarded as relating to protection of the rights thus given. At all events, there is nothing in it to satisfy me that it should influence the construction of the complainant's rights, as here contended for.

It is not necessary to determine what right, if any, the complainant may have in common with the public to take water from the Passaic for the uses to which it devotes it. If such a right is enjoyed, it is a common right, the interference with which, by pollution of the water, does not work a private, direct, and material damage to the complainant distinct from that which is suffered by the public at large, and which is necessary to enable an individual to maintain such a bill as that which is before me. It is true the injury to the complainant may be greater than to others of the public, because the complainant makes extensive use of the water for purposes which will not admit of its pollution, while others may make but little similar use of it, and others yet may not use it at all. But the injury to all is in its character and essence the same; the difference is only in degree. In the absence of the distinct injury to the complainant, it cannot maintain this suit. Where a nuisance is purely public, the proceeding in this court to restrain it must be by information by the attorney general. The statutory authority under which it is insisted the complainant may maintain this suit is contained in the sixth section of the act of 1860, above referred to. That section provides "that the Newark Aqueduct Board" may prosecute an action or process at law or in equity against any person for money for the use of water, for the breach of any contract, "and also for any injury or trespass or nuisance done, or caused or procured to be done, to the water-courses, pipes, machinery, or any apparatus belonging to or connected with any part of the works, or for any improper use or waste of the water." As the control and management of all that per-

tains to Newark's water supply was committed to the complainant board, it became convenient and proper that it should be enabled to make contracts and enforce compliance with them, and at the same time to protect the property placed in its charge. For these purposes it was given a corporate name and existence, but I find nothing in this legislation which clothes the complainant with power to do more than an individual could do in the protection of his own property. It does not authorize proceedings either in the name of the state or in the name of the attorney general. The injury contemplated was evidently injury to private rights only. It was to apparatus, pipes, machinery, and water-courses connected with the complainant's works; that is, injury to water-courses in which the complainant's principal had some special right of property. The legislation evidently was designed to bestow a corporate existence upon the aqueduct board for certain purposes, and, among them, to maintain suits in its own name for the protection of the property intrusted to it in the same manner as an individual owner of that property might sue for his own protection. The conservation of public interests is with the state and its attorney general, and its bestowal by the legislature upon another agency, like the grant of public domain, should be by express language, or, at least, by that from which the power must be necessarily implied.

It follows, from the views that I have taken of the questions thus far considered, that the complainant has not shown either authority to maintain this suit in behalf of the public, or such distinct special rights in the waters of the Passaic river as this court will feel bound to protect, or, at best, that it has uot shown such authority and rights established by adjudication in this state. "No rule of equity," says Chief Justice BEASLEY, in Coach Co. v. Railroad Co., 29 N. J. Eq. 299, 304, "is better settled than the doctrine that a complainant is not in a position to ask for a preliminary injunction when the right on which he founds his claim is, as a matter of law, unsettled." And in the late case of Haggerty v. Lee, 45 N. J. Eq. 255, 17 Atl. Rep. 826, Mr. Justice DEPUE reiterates the rule thus stated, in this language: "It is impossible to emphasize too strongly the rule so often enforced in this court, that a preliminary injunction will not be allowed where either the complainant's right which he seeks to have protected *in limine* by an interlocutory injunction is in doubt, or where the injury which may result from an invasion of that right is not irreparable."

It has been urged that the consequences of the contemplated drainage will be so disastrous and irreparable that I should not dismiss this application without consideration of its merits, and giving some expression of opinion as to them. It is a well-settled rule of equity procedure that an injunction to restrain a nuisance will issue only in cases where the fact of nuisance is made out upon determinate and satisfactory evidence. If the evidence be conflicting, and the injury be doubtful, that will constitute a ground for withholding the injunction. 2 Story, Eq. Jur. § 924*a*; Attorney General v. Heishon, 18 N. J. Eq. 410. And, where the interposition by injunction is sought to restrain that which it is apprehended will create a nuisance, the proofs must show that the apprehension of material and irreparable injury is well grounded upon a state of facts which show the danger to be real and immediate. Brookline v. Mackintosh, 133 Mass. 215. The complainant grounds its apprehension of danger from the defendant's sewage, if discharged into the river, largely upon the opinion of Peter T. Austen, who is employed by it as its chemist, and who is also a professor of chemistry in Rutgers College, at New Brunswick, in this state. This gentleman, assuming that both floating and dissolved matter discharged into the Passaic river will reach the Newark water intake within a few hours after its discharge, and be pumped into the reservoir and distributed to the people of Newark, proceeds to discuss the effect of the use of such polluted water upon the health of its consumers. He says: "Experimental science has established the fact that a large number of diseases are communicated from one person to another by means of minute organisms known as *microbes*, *bacteria*, *baccilli*, *micrococci*, etc., or more popularly as germs. The communicability of disease, as in cases of small-pox, scarlet fever, diphtheria, syphilis, etc., is well understood by the public. The germs or virus of these diseases comes in contact with the proper membranes, and proceed at once to develop and cause the specific functional disorders known as disease. There is good evidence to show that disease may also be communicated by water, if the water contains disease germs." The affiant then refers to instances in which the prevalence of typhoid fever in a community was attributed to the *excreta* of the typhoid fever patient in water from which the inhabitants drank. He thinks that the albuminoid matter in sewage in sufficient quantity, and under favorable circumstances, will feed disease germs, and multiply them, and that the putrefaction and decomposition of the albuminoid substances may produce poisonous nitrogenous substances deleterious to health. He further stated that although

a portion of the solid matter in sewage may sink to the bottom, or become entangled with the vegetation on the banks of the river, the soluble matter will still pass on, and the solid matter that sinks or becomes entangled may soon ferment, putrefy, and decompose, and impart to the water its products, and that in process of decomposition gases will be generated which will cause the solid matter that contains them to float with the current.

In addition to this affidavit the complainant produced the depositions of Charles Jacobson, its civil engineer, and two of its water inspectors, which show that in October, 1888, Mr. Jacobson, accompanied by the two inspectors, went to a point in the Passaic river, at about the place where the defendant proposes to discharge its main sewer, at a time when the tide in the river was at full ebb flow, and the volume and current was at about the average, and when little or no wind was blowing, and placed four tin floats in the water, and then followed them in their course down the stream. Three of the floats became entangled in grass along the shore of the river, but the fourth went to the intake of the water for Newark, a distance of about 24,300 feet, in four hours and two minutes.

In reply to the affidavit of Professor Austen, and in support of the answer's denial that the discharge of its sewage will pollute the waters of the Passaic river or create a nuisance therein, the defendant produced the deposition of Henry Wurts, formerly state chemist of New Jersey. Mr. Wurts states that he is by profession a chemist, and that for the last 17 or 18 years he has made special study of the waters of the Passaic river, and many analyses of them. Speaking of such analyses made by him in 1881 and 1882, he says: "These analyses were so planned as to follow up the changes that might take place in the composition of the river from above Passaic Falls down to the outlet of the Dundee canal into the tidal channel at Passaic, showing the effect on the sewage of Paterson if flowed through the open air. Above the falls, the total amounts of nitrogen in the water in all forms by three analyses, made at intervals of some weeks, were .0217, .0286, and .0389, and in the mean .0297, grain per gallon, while at four and a half miles below the falls, at the Broadway bridge, the figures were .025–, .0315, and .0363, in the mean .0309,—only 4 per cent. more than above the falls. Thus in this four and a half miles of flow almost the whole effect of the sewage of Paterson (then having at least 50,000 people) had disappeared. This is an absolute loss and destruction of the noxious matter, as these impurities must pass off into the air as ammonia and gaseous nitrogen. Even such portion of it as is assimilated by plants and animals living in the water becomes thereby innocuous, and ultimately passes into the air in these same gaseous forms." The affiant declares it to be his opinion, substantiated by the result of his analyses, that the nitrogenous and putrescible constituents of the sewage of the city of Passaic will substantially vanish during the down flow of four and a half miles from the sewer outlet to the Newark intake. He also states that on the 25th of April, 1889, he examined the sewers of the city of Newark that empty into the Passaic river, and found that they number seven, and that the nearest of them to the Newark water intake is that which is called "Second River," two and a quarter miles below the pumping station. At the foot of Clay street he found two brick tunnels discharging directly into the river "streams of black opaque water," having a thick, offensive-looking scum upon it. This sewer is three and a quarter miles below the water intake, and discharges about 2,000,000 of gallons of sewage during the 12 business hours of each day. He further states that the tide in the river carries a portion of this sewage to the Newark intake, and that his analyses establish that seventeen-eighteenths of the present pollution of the water at that intake is caused by the Newark sewage. It is also shown that at the defendant's proposed sewer outlet the Passaic river is about 200 feet wide, and 14 feet deep in the channel, at high tide, and that because the United States government has removed the bars in the river the sewage will be swept back and forth by the continual ebb and flow of the tide, and that the tide flows above the outlet of the sewer for a mile and a half, at the end of that distance rising about three and a half feet. It is argued that the flow of each tide will send the sewage back this distance diluted in a great body of water, and that the greater part of it will thus be obliged to traverse a much greater distance than four and a half miles before it can reach the Newark intake; and it is insisted that if the Paterson sewage from 50,000 population disappears in a flow of four and a half miles above tide-water, that the sewage in question, from only 10,000 population, must more certainly vanish in this greater flow, added to a washing by the tide.

In the case of Attorney General v. Board, L. R. 18 Eq. 172, in 1874, I find that Sir GEORGE JESSEL, M. R., dealt with testimony by Dr. Frankland, of the Royal College of Chemistry in England, which was somewhat similar to that which is here given by Professor Austen. There Dr.

Frankland said that no sewage could be admitted into a river without deteriorating the quality of the water. "The deterioration," he said, "for washing and manufacturing purposes, may be, as in this case, insignificant or imperceptible; but for drinking and cooking such water becomes dangerous, because, as the rivers pollution commissioners have shown, the sewage matter is not perceptibly altered in its character by a flow of seven miles, and scarcely diminished in quantity. Neither does the failure of chemical analysis to detect any deleterious ingredient indicate that danger is absent, since the nature of the noxious ingredients which propagate small-pox, scarlet fever, typhoid fever, or cholera is unknown. A chemical analysis is therefore powerless to detect these ingredients." In the case before me Professor Austen speaks of these ingredients as germs of disease called "microbes;" that is, germs so infinitesimal that they derive their name, "microbes," from the powerful glass by the aid of which it is claimed they may be detected. The theory advanced by Dr. Frankland was contradicted by other experts, and the Master of the Rolls, because no impurity was detected in the intake of the Workington water-works, declared that a nuisance was not proven.

In Goldsmid v. Commissioners, L. R. 1 Ch. 349, Lord Justice TURNER, referring to the testimony of scientific experts in a case of nuisance, said: "Speaking with all possible respect to the scientific gentlemen who have given their evidence, and as to whom it is but just to say that they have dealt with the case most ably and most impartially, I think that in cases of this nature much more weight is due to the facts which are proved than to conclusions drawn from scientific investigations. The conclusions to be drawn from scientific investigations are, no doubt, in such cases, of great value, in aid or in explanation and qualification of the facts which are proved, but in my judgment it is upon the facts which are proved, and not upon such conclusions, the court ought in these cases mainly to rely. * * * In my view of this case, therefore, the scientific evidence ought to be considered as secondary only to the evidence as to the facts."

This view of scientific evidence in cases of this kind so commends itself to me that I am constrained to be guided by it in the disposition of the question of fact I am now considering. The application here is to restrain that which it is alleged will create a nuisance, not that which in fact creates a nuisance. The injury is prospective, and it is only possible to judge from experience in similar cases, experiment, and the opinions of experts, whether the apprehension is well grounded and free from doubt. Here two important circumstances appear—*First*, practically all traces of the Paterson sewage, as far as the same could be detected by chemical analysis, had disappeared in the flowing water of the Passaic, four and a half miles from the place at which it was discharged into the river, although in that part of the river there was no flux and reflux of the tide; and, *second*, the sewage of Newark, washed by the tide to the Newark water intake, readily detectable by chemical analysis, has not produced an injury similar to that which is apprehended from this much smaller quantity of sewage, to be emptied into the river at a much greater distance from the intake. In the light of these circumstances, it may be asked why, if imperceptible germs of disease, fraught with danger to health and life, continue in water after all traces of the sewage from which they come, so far as they can be detected by the chemist, are lost, have not their dangerous qualities become manifested in Newark long before this? This experience seems to be a complete negation of the danger theory advanced in support of this application, or is sufficient, at least, to render it doubtful whether the danger apprehended is more than chimerical. I deem it of sufficient weight to justify me in withholding a preliminary injunction.

With reference to the Newark sewage, I should add that it is not a sufficient ground for refusal of the injunction asked to say that the Newark sewage is a greater and more dangerous nuisance than the sewage of the city of Passaic will be, and because it pollutes the river the court will not restrain the small addition to that pollution that the sewage of Passaic will make. The defendant would have no right to add to existing pollution, even though it be proportionally much less than that which exists. Attorney General v. Steward, 20 N. J. Eq. 415; Attorney General v. Corporation, L. R. 5 Ch. 583; Attorney General v. Asylum, L. R. 4 Ch. 146. I will discharge the order to show cause, and deny the complainant's application.

Application for an injunction was again made in 1890 and a large additional amount of evidence taken in the fall of that year. The decision is still pending.

APPENDIX VI.

THE following is the Pollution Prevention Act passed by the Virginia Legislature in 1892:

AN ACT to prevent the pollution of potable water used for the supply of cities. Approved Feb'y 29, 1892.

1. Be it enacted by the General Assembly of Virginia, That it shall be unlawful, except as hereinafter provided, for any person to defile or render impure, turbid, or offensive the water used for the supply of any city or town of this state, or the sources or streams used for furnishing such supply, or to endanger the purity thereof by the following means, or any of them, to wit: by washing, or bathing therein, or by casting into any spring, well, pond, lake, or reservoir from which such supply is drawn, or into any stream so used, or the tributary thereof above the point where such supply is taken out of such stream, or is impounded for the purposes of such supply, or into any canal, aqueduct, or other channel or receptacle for water connected with any works for furnishing a public water supply, any offal, dead fish, or carcass of any animal, or any human or animal filth, or other foul or waste animal matter, or any waste vegetable or mineral substance, or the refuse of any mine, manufactory, or manufacturing process, or by discharging or permitting to flow into any such source, spring, well, reservoir, pond, stream, or the tributary thereof, canal, aqueduct, or other receptacle for water, the contents of any sewer, privy, stable, or barnyard, or the impure drainage of any mine, any crude or refined petroleum, chemicals, or any foul, noxious, or offensive drainage whatsoever, or by constructing or maintaining any privy vault or cesspool, or by storing manure or other soluble fertilizer of an offensive character, or by disposing of the carcass of any animal, or any foul, noxious, or putrescible substance, whether solid or fluid, and whether the same be buried or not, within two hundred feet of any watercourse, canal, pond, or lake aforesaid, which is liable to contamination by the washings thereof or percolation therefrom; provided, that nothing in this act contained shall be construed to authorize the pollution of any of the waters in this state in any manner now contrary to law; and provided further, that this act shall not apply to streams the drainage area of which, above the point where the water thereof is withdrawn for the supply of any city or town, or is impounded for the purposes of such supply, shall exceed fifty square miles.

2. That any person knowingly or wilfully violating the terms of this act shall be deemed guilty of a misdemeanor, and shall be punished for each offence by a fine not exceeding one hundred dollars, or by imprisonment not exceeding thirty days, or by both, at the discretion of the court, and provided further, that nothing herein contained shall be so construed as to prevent the washing of ore or minerals in any of the streams or waters of this commonwealth other than such as may be used for the water supply of any city or town.

3. This act shall take effect fifteen days after its passage.

APPENDIX VII.

THE following are the Rules of the New York State Board of Health governing the preparation of such plans for Sewerage and Sewage Disposal Works as are required by law to be submitted to the Board for approval:

The experience of the past year has shown the necessity for a statement of what the Board requires to be conveyed by the plans submitted, and of the most desirable form that these plans should take. The following suggestions are therefore made, and it is requested that those inter-

ested with the preparation of plans will follow them as closely as is practicable. Certain portions must be followed, while considerable latitude can be allowed upon others, as intimated.

1. A plan of the entire village will be required, showing all streets, and so far as practicable proposed streets. This must not be on a smaller scale than 250 feet to an inch and may be larger. A comprehensive title, stating what the map purports to show, must be placed thereon. The scale of the map must be distinctly stated, and an explanation of all symbols used must be given on it. Contour lines should be carefully located and drawn to interfere as little as possible with the delineation of other features. A sufficient number of elevations above an assumed datum, written in figures, should be given to show the governing elevations of the ground. The elevations of sewer invert at critical and other important points should be given, each surmounted by an oval as a distinguishing mark. When the plan presented does not propose to sewer the entire village, and the street profiles do not extend to the ends of the streets or to the village limits, the elevations of the grouud at every change of slope in the streets beyond the limits of the profiles, and the elevations of the bottoms of the deepest cellars, or other localities below the level of the street, should be given in their proper locations upon the plan. Upon this plan must be shown all existing sewers, with all the information obtainable regarding their depth below the surface, grades, sizes, mau-holes, lamp-holes, catch-basins, flush-tanks, etc. The proposed system must be laid down in a clear and definite manner, showing the locations of the lines in the streets, the position of man-holes, catch-basins, lamp-holes, inspection-pipes, flush-tanks, ventilators or other appurtenances, by symbols readily distinguishable and explained in the map-legend. The sizes of pipe and the grades of inclination must be given in figures alongside the line, and points of change of inclination or of alignment must be definitely located, being part of the information given by the profiles, here repeated as a great convenience. Inclinations may be given as fall in feet per hundred or as a slope ratio. A sufficient number of arrows must be drawn alongside the lines to show clearly the direction of flow of sewage. The position of outlet must be clearly shown, and the direction of current in the body of water, if any, into which the sewage flows. Location of disposal works must also be shown. Independent lines of pipe proposed for subsoil or cellar drainage should be marked by a different symbol from that for tight sewer pipe lines, and the size of such pipes should be given. When the territory covered by the village is large the details of sewers may be given on one or more sheets on the large scale, the entire village being shown on an accompanying map of a convenient smaller scale, which shall contain the general information required above.

2. Profiles of the streets proposed to be sewered and of other lines of sewer must be presented on separate sheets from the plan. These profiles should be extended to the entire length of the street and should be presented for every street in the village, unless the elevations beyond the ends of proposed sewer lines are placed on the plan as proposed in paragraph 1 above. These profiles should show the profile of ground surface, the elevation of particularly low points, such as cellar bottoms, low lots, etc., and their distances from the sewer line, and the grade line of the sewer. Location of man-holes, lamp-holes, catch-basins, flush-tanks, and other sewer appurtenances should be shown, also points of intersection with other streets and points of entrance of branches, with their elevations at entrance. Inclination of sewer should be given in figures, also points of change of inclination being clearly defined. A small title should appear on each sheet of profiles, giving at least name of village, scales and explanation of symbols.

3. Details of the general plans for constructions connected with the sewers, such as man-holes, catch-basins, lamp-holes, inspection pipes, junctions, valves, traps, should be given, and full drawings of any devices for special purposes demanded by the peculiar circumstances of the case. Sections of sewers other than circular should be shown. Full details of the outlet should be given, and plans, elevations, sections and details of special grounds, buildings, machinery or other apparatus used in connection with the disposal of the sewage and drainage. Definite scales for these details cannot be prescribed. It is necessary that the scales used be large enough to present the information clearly and definitely, and plenty of room should be left between drawings, that they may not be unintelligible on account of crowding. It will be better to present the details on one or more sheets separate from the plans and profiles. Titles and subtitles enough to give name of village, explanation of symbols, names of objects delineated and scales should appear on each sheet of details.

4. General specifications for the construction of the system must accompany the plans, giving the general requirements and conditions regarding trenching, draining material, inspection and laying of pipe, character of materials and manner of construction of brick sewers and of man-

holes, flush tanks, outlets and other appurtenances. The specifications intended for contractors may be presented as fulfilling the above requirements, if considered desirable.

5. Duplicates of plans, profiles, details and specifications must be presented. The original will be returned to the sewer commissioners upon approval, with the official statement of that approval. The duplicate will be filed according to law, in the office of the State Board of Health. The originals may be in any color desired. As portions at least of each set of plans will be reproduced for the annual reports, it is quite necessary that the duplicates be drawn in black only, the distinction between lines being made by different forms of line rather than by colors. They must be as perfectly clear and definite as the originals, and may be upon tracing cloth. Red lines may be used if the ink is ground from a body color. Aniline red must not be used.

6. A report should be presented, written probably by the designing engineer, giving the data upon which calculations and locations were made, such as area, population, distribution, estimated increase in population, rainfall, amount of surface drainage to be taken care of and method of disposing of it, amount of roof-water, amount of sewage, and basis for the estimates of these amounts, a statement of such points as are peculiar to the locality, a description of devices for special purposes, and such other information as may be deemed necessary to a complete understanding of the plans as presented. This report should also give a general statement of the reasons for choice of system and of the method of disposal of sewage and drainage, an explanation of any special features connected therewith, and a statement of the proposed manner of maintaining the works, where a purification plant is intended. A tabular statement of the amounts of water and sewage to be disposed of by each sewer branch and main will be found the shortest and most convenient manner of presenting the major part of the information above required.

APPENDIX VIII.

AN ACT to Prevent the Pollution of Rivers and Sources of Water Supply.—Chapter 225, Laws of 1885. Approved, March 7, 1885.

To be enacted by the Legislature of the State of Minnesota:

SECTION 1. No sewage, drainage or refuse or polluting matter of such kind as either by itself or in connection with other matter will corrupt or impair the quality of the water of any spring, well, pond, lake, stream or river for domestic use, or render it injurious to health, and no human or animal excrement shall be placed in or discharged into, or placed or deposited upon the ice of any pond, lake, stream or river, used as a source of water supply by any town, village or city; nor shall any such sewage, drainage, refuse or polluting matter or excrement be placed upon the banks of any such pond, lake, stream or river within five miles above the point where such supply is taken, or into any feeders or the banks thereof, of any such pond, lake, stream or river.

SEC. 2. The State Board of Health shall have the general supervision of all springs, wells, ponds, lakes, streams or rivers used by any town, village or city as a source of water supply, with reference to their purity, together with the waters feeding the same, and shall examine the same from time to time and inquire what, if any, pollutions exist, and their causes. In case of the violation of any of the provisions of section one (1) of this act, said Board may appoint a time and place for hearing parties to be affected, and shall give due notice thereof, as hereinafter provided, to such parties, and after such hearing, if in its judgment the public health requires it, may order any person or corporation or municipal corporation to desist from the acts causing such pollutions, or to cleanse or purify the polluting substance in such a manner and to such a degree as shall be directed by said Board, before being cast or allowed to flow into the waters thereby polluted, or placed or deposited upon the ice or banks of any of the bodies of water in the first section of this act mentioned. Upon the application of the proper officers of any town, village or city, or of not less than ——— legal voters of any such town, village or city, to said Board, alleging the pollution of water supply of any such town, village or city by the violation of any of the provisions of this act, said Board shall investigate the alleged pollution, and shall appoint a time and place when and where it will hear and examine the matter, and shall give notice

of such hearing and examination to the complainant, and also to the person or corporation or municipal corporation alleged to have caused such pollution, and such notice shall be served not less than ten (10) days prior to the time so appointed, and shall be served in the same manner that now is or hereafter may be by law provided for the service of a summons in a civil action in the district court. Said Board, if in its judgment any of the provisions of this act have been violated, shall issue the order or orders already mentioned in this section.

SEC. 3. The district court, or the judge thereof, may, upon the complaint of said Board, or of the proper authorities of any town, city or village, whose sources of water supply shall be so polluted, issue an injunction to enforce the orders of said Board.

SEC. 4. Such orders of the State Board shall be served upon the persons, corporations or municipal corporations found to have violated any of the provisions of this act, and any party aggrieved thereby shall have the right to appeal to the district court of the county in which is situated the town, village or city, whose source of water supply is found to have been polluted, and such aggrieved party shall have the right to a trial by jury in the same manner as in a civil action in said court. During the pendency of the appeal, the pollution against which the order has been issued, shall not be continued contrary to the order of the State Board, and upon the violation of the order the appeal shall be forthwith dismissed.

SEC. 5. Any person, corporation or municipal corporation desiring to appeal from any such order of the State Board, shall, within thirty (30) days after the service upon him or it, of a copy of such order, file in the office of the clerk of the district court of the proper county, a notice of such appeal, together with a bond in the sum of not less than two thousand (2,000) dollars, with two (2) sureties, to be approved by the judge of said court, conditioned for the prosecution of such appeal to judgment, and for the payment of all the costs and disbursements that may be adjudged against him or it therein, and shall, within three (3) days after such filing, serve a copy of such notice and bond upon the Secretary of the Board; said Secretary shall within ten (10) days thereafter, deliver such copies so served upon him to the Mayor or other chief executive officer of any such city, village or town, whose source of water supply has been found to have been so polluted.

SEC. 6. Water boards, water commissioners, water companies and the proper officers of any city, village or town, making use as a source of water supply, of any well, spring, pond, lake, stream, river, reservoir or well, within, or partly within, this State, and distributing the waters thereof for public, domestic and general uses, shall, from time to time, and whenever required by said Board, make returns to said Board, upon blanks to be furnished by it, of such matters as may be required by said Board and called for by such blanks, and any such water board, water commissioners, water company, or officers of any city, village or town, who shall for the space of thirty (30) days after being furnished with such blanks, fail or neglect to make any such report so required, shall for each and every such neglect or failure, forfeit and pay the sum of one hundred (100) dollars, for the use of the local Board of Health, or the proper officers acting as such, of the city, town or village where such delinquent has its principal office. Said State Board shall, in the name of the State, prosecute in the district court of the proper county an action for the recovery of the penalty or forfeit therein imposed.

SEC. 7. This act shall take effect and be in force from and after its passage.

INDEX.